GEOLOGY OF A LOWER PROTEROZOIC VOLCANICLASTIC SEQUENCE NEAR WAUSAU, MARATHON COUNTY, WISCONSIN

A Thesis Submitted to the Faculty of the Graduate School
of the University of Minnesota

by

COLIN LEE REICHHOFF

In Partial Fulfillment of the Requirements
for the Degree of
Master of Science

June 1986

ABSTRACT

A sequence of Lower Proterozoic (1859 m.y.) volcanic and volcaniclastic rocks is exposed in the vicinity of Brokaw, north of Wausau, in Marathon County, Wisconsin. These rocks were mapped in detail and sampled for petrographic study. This sequence has been metamorphosed to lower greenschist facies and is only mildly deformed, dipping to the west at 10-30^{o}.

Based on rock type, the study area can be divided into three segments. The easternmost and westernmost seqments are poorly exposed; they consist mainly of intermediate to felsic lava flows and pyroclastic rocks. Basaltic rocks are only minor components of these two segments. The central segment contains the best exposures, and consists mainly of sedimentary and pyroclastic rocks. The stratigraphy of this segment, from oldest to youngest, consists of red sandstones and pebble conglomerates, thinly bedded siltstones and tuffs, pyroclastic deposits and greenish-black sandstones and conglomerates.

The greenish-black and red sandstones and conglomerates are interpreted as fluvial sediments deposited by a braided river system. Paleocurrent study of the greenish-black sandstones indicates the sediment source was to the E-SE. The red sandstones are composed mainly of felsic volcanic rock fragments and quartz with only small amounts of plagioclase; plutonic rock fragments are very minor components. The greenish-black sandstones contain more felsic to intermediate volcanic rock fragments and roughly equal amounts of quartz and plagioclase; plutonic rock fragments and quartzite grains represent 1-3% of these sediments. The modes of the two sandstone units, when plotted on QFL and QmFLt diagrams (after Dickinson and Suczek, 1979) indicate the sediment

was derived from a magmatic arc-type setting. An increase in the percentage of plutonic and quartzite grains in the greenish-black sandstones, compared to the red sandstones, suggests an increased depth of erosion and the input of material from outside the magmatic arc. The thinly bedded siltstones and tuffs represent lacustrine sediments associated with the fluvial system.

Three pyroclastic units are present in the southern half of the central segment, and are apparently unconformably overlain by the greenish-black sandstones. These pyroclastic units overlie the thinly bedded siltstone and tuff unit and include; a unit varying from lithic-rich at its base to crystal-rich near its top, a block-and-ash flow, and a welded dacite tuff.

The association of fluvial and lacustrine deposits and the dominance of ash and lapilli tuffs, with only minor pyroclastic breccias, suggests this sequence represents an intermediate-source facies (Fisher and Schmincke, 1984) within the volcanic field. The intermediate-source facies is comparable to the dispersal facies of Dickinson (1974) and is found at distances > 5 km from the central vent.

The depositional setting for this sequence of rocks is interpreted as a small restricted basin within a continental margin magmatic arc (intra-arc basin). These rocks were deposited following the main phase of deformation associated with the Penokean Orogeny.

ACKNOWLEDGEMENTS

The author wishes to thank Dr. R. W. Ojakangas of the University of Minnesota-Duluth for serving as principal thesis advisor, and Drs. R. L. Morton, J. C. Green and D. P. Poe for serving as thesis committee members.

Dr. G. L. LaBerge of the University of Wisconsin-Oshkosh deserves recognition for his insight and contagious enthusiasm regarding the geology of Wisconsin and the Lake Superior region.

B. Kramer of 3M's Minerals Division provided access to the 3M quarry at Wausau, Wisconsin.

Funding for this project was provided by Dr. K. J. Schulz of the U. S. Geological Survey.

Deepest appreciation is also expressed to my wife Jayne and to my family for their continued moral support.

TABLE OF CONTENTS

Page

LIST OF ILLUSTRATIONS

Figures | Page

Figures Page

Tables Page

Plates

I. INTRODUCTION

LOCATION and GEOGRAPHY

The area of study is located approximately 6 km north of Wausau in Marathon County, Wisconsin (Fig. 1). This area covers about 21 km^2 and includes the town of Brokaw which is located on the Wisconsin River. The study area is very accessible with U.S. Highway 51 running north-south through the center, County Highway K along the western and southern border, and County Highway WW cutting east to west through most of the area. Many smaller roads also transect the area allowing easy access.

The topography in the Brokaw area ranges from gently rolling to rugged hills and valleys. Topographic relief is due to the dissection of the Precambrian bedrock by the Wisconsin River, Lentz Creek and by several smaller streams and tributaries. Maximum relief is found along the Wisconsin River with up to 250' difference in elevation from normal river level to the tops of nearby hills along its banks. The Wisconsin River bisects the study area into eastern and western parts.

A thin sheet of glacial till and alluvium covers the entire area so outcrops are relatively sparse; the best exposures are found in roadcuts and along rivers. Most of the land in the area is privately owned and is devoted to timber and to farming, most notably ginseng for export.

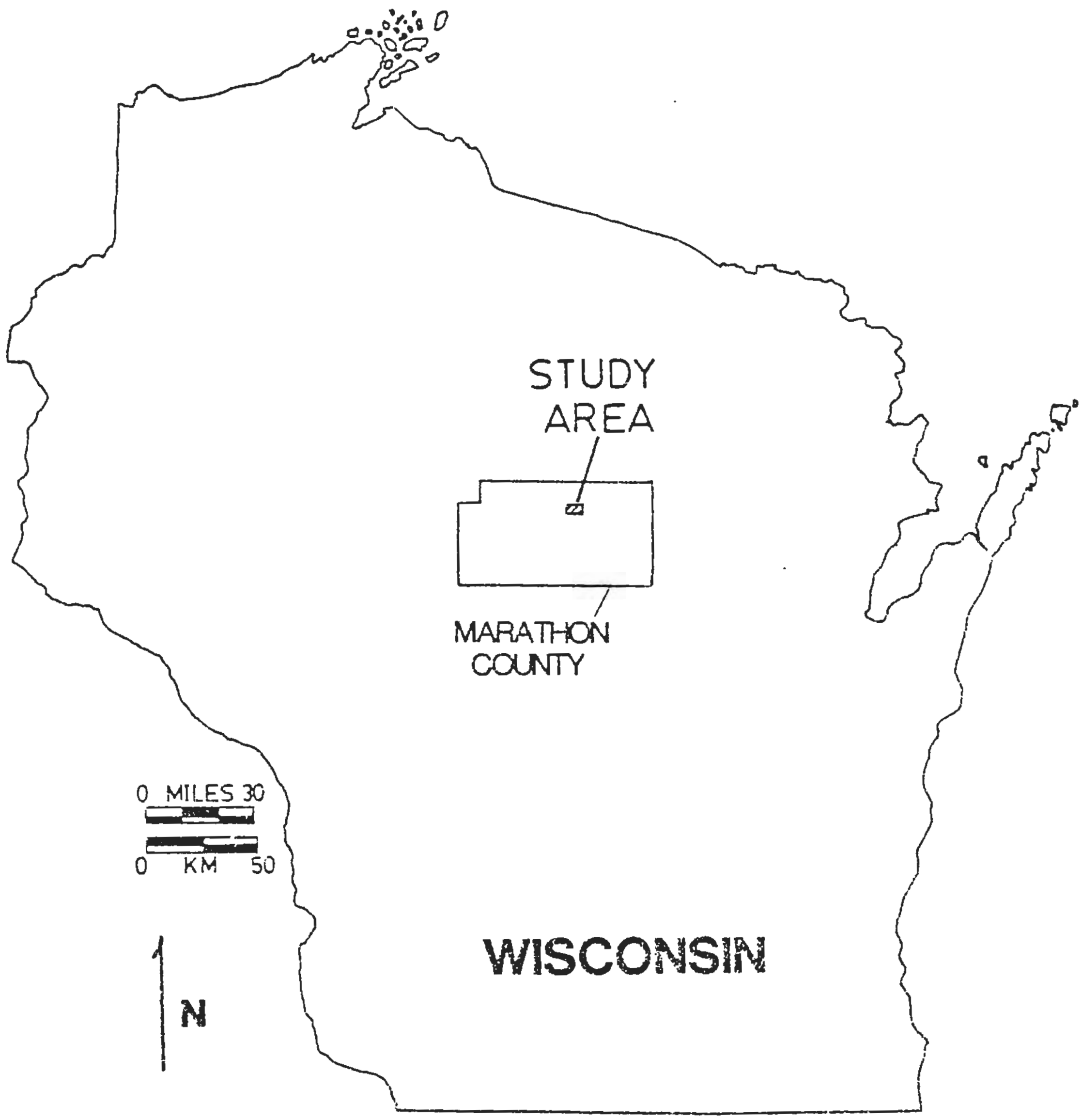

Figure 1: Index map of Wisconsin showing Marathon County and location of study area.

This area is roughly rectangular and lies entirely within T. 29 N., R. 7 E., and T. 30 N., R. 7 E., on the Brokaw, WI 7.5 minute quadrangle and T. 29 N., R. 7 E., T. 30 N., R. 7 E., T. 29 N., R. 8 E., and T. 30 N., R. 8 E., on the Nutterville, WI 7.5 minute quadrangle.

OBJECTIVES of STUDY

The rocks in the Brokaw area represent a small confined sequence of moderately to poorly exposed volcanic and volcaniclastic rocks of early Proterozoic age (1859 m.y.). These rocks are in both intrusive and fault contact with younger 1500 m.y. plutonic rocks. The youngest intrusive unit in contact with the sequence includes the Wausau and Stettin Syenites which are related to the Wolf River batholith. The next oldest unit is the Granite Heights Granite, a pluton that ranges in composition from quartz monzonite to granite. These plutonic rocks are both intruded into and faulted into contact with the older volcanogenic rocks of the study area. The volcanic sequence contains rocks of various lithologies including: dacitic to rhyolitic lava flows, dacitic to rhyolitic welded and non-welded tuffs, mafic dikes, amygdaloidal and massive basalt, tuffaceous siltstones, volcanic sandstones and conglomerates.

This volcanic sequence had been recognized in the past but had never been studied in detail. The purpose of this investigation was to study both the volcanic and the sedimentary rocks of the Brokaw area which are part of the poorly understood Proterozoic volcanic sequence in Wisconsin. The objectives were as follows:

1) To map in detail (scale 1:12,000) the available outcrops and to produce a geologic map of the area.
2) To study the rocks of the area petrographically and chemically.
3) To interpret these rocks and to define the environments in which these volcanic rocks and volcaniclastic sediments were deposited.

METHODS of STUDY

Approximately 45 days were spent in the field during the summer of 1984, and 25 days during the Fall, Winter and Spring of 1984 and 1985. Field work consisted of locating outcrops and mapping at a scale of 1:12,000 on a base map prepared from parts of the Brokaw and Nutterville, WI 1:24,000 sheets. While in the field, LaBerge and Myers' (1983) 1:100,000 scale geologic map of Marathon County was used as a reference for known outcrop locations, gross lithology and location of study area boundaries.

The most informative exposures in the area are found in roadcuts and river cuts. Numerous previously unmapped exposures were located in wooded areas. The objectives of the field mapping were to: locate and examine all exposures in the area, determine the structural attitude of the units, collect samples to be studied petrographically and chemically, take paleocurrent measurements, and measure the stratigraphic thickness of several exposed sections.

A total of 130 rock samples were collected and studied petrographically; all slabs were stained for potassium feldspar and plagioclase using sodium-cobaltinitrate and alizarin red. Igneous rocks were named according to the classification of Williams, Turner and Gilbert (1984). Four chemical analyses were available from the U.S. Geological Survey and two from a previous study. The IGPET program of M. Carr was useful in geochemical interpretation.

PREVIOUS WORK

One of the first studies of the rocks of the Brokaw area was done by Weidman (1907) as a geologist for the Wisconsin Geological and Natural History Survey. This study, which covered all of north-central Wisconsin, was the first comprehensive compilation of the geology of this area and included descriptions of several rock units located in this study area. Weidman's study grouped the conglomerates and graywackes (Marshall Hill graywacke and conglomerate) with similar sedimentary rocks in the region such as the Mosinee Conglomerate and the Marathon City Conglomerate. The relationships between these units were and still are unclear but they were presumed by Weidman to be contemporaneous.

He termed these rocks the Upper Sedimentary Series and he placed them at the top of the Precambrian geologic column indicating a possible middle Huronian age. Weidman suggested the Upper Sedimentary Series was unconformably underlain by three igneous units which are, from youngest to oldest: the Granite-Nepheline Syenite Series, the Gabbro-Diorite Series and the Rhyolite Series. These groups were described in outcrop and in hand specimen and outcrop locations were shown on township maps. The sequence of sediments in the current area of study were grouped with the Upper Sedimentary Series, but are apparently older than Weidman's Granite-Nepheline Syenite Series as they are intruded by the Stettin and Wausau syenites on the western and southern margin of the study area.

Emmons and Snyder (1944) did a structural study of the rocks in the Wausau area. This study dealt mainly with the nepheline occurrences in the syenites. They also described what they considered argillite and agglomerate within the current area of study. They differentiated three types of argillite -- banded, massive and sericitized-- with the banded type being the most common. They considered the rocks of the Brokaw quarry to be a very quartz-rich variety of argillite. The agglomerate was located in two places and looked very similar to conglomerate but with mainly volcanic components and angular fragments in the matrix.

Asquith (1963) studied the Precambrian rhyolites of

Wisconsin and included samples from the Brokaw quarry in his study. The goal of this study was to examine the structures found in these volcanic rocks in order to determine the method of emplacement, either as lava flows or as welded tuffs. He concluded that the rocks found in the Brokaw quarry were pyroclastic in origin, based on the lack of lava flow textures, the presence of relict glass shards and the occurrence of bedding in some of the units. Van Schmus, Thurman and Peterman (1975) and Van Schmus (1980) have worked on the geochronology of the rocks found in eastern and central Wisconsin. These studies included age dating by Rb/Sr and U/Pb methods of two rock units associated with the study area: the Granite Heights granite and a rhyolite porphyry located to the south of the study area and considered an extension of the volcanic sequence. The U/Pb method indicates an average age of 1859±20 m.y. for the volcanics; the Rb/Sr method indicates an average age of 1640±45 m.y. for the volcanics and an approximate age of 1615 m.y. for the Granite Heights granite. The Rb/Sr dates are considered too young, likely due to the resetting of the Rb/Sr clock during a presumed low grade metamorphic event between 1700 and 1600 m.y. (Van Schmus, 1980).

LaBerge and Myers (1983) have studied Marathon County including this area. Their study includes a geologic map of Marathon county at a scale of 1:100,000 that shows major outcrops. Their page-size geologic map (Fig. 2) indicates the tectonic complexity of the region, which underwent several periods of volcanism, plutonism and sedimentation during the Proterozoic. Extensive faulting and shearing of the rocks of Marathon County has also been documented but has been disputed by Maass (1983).

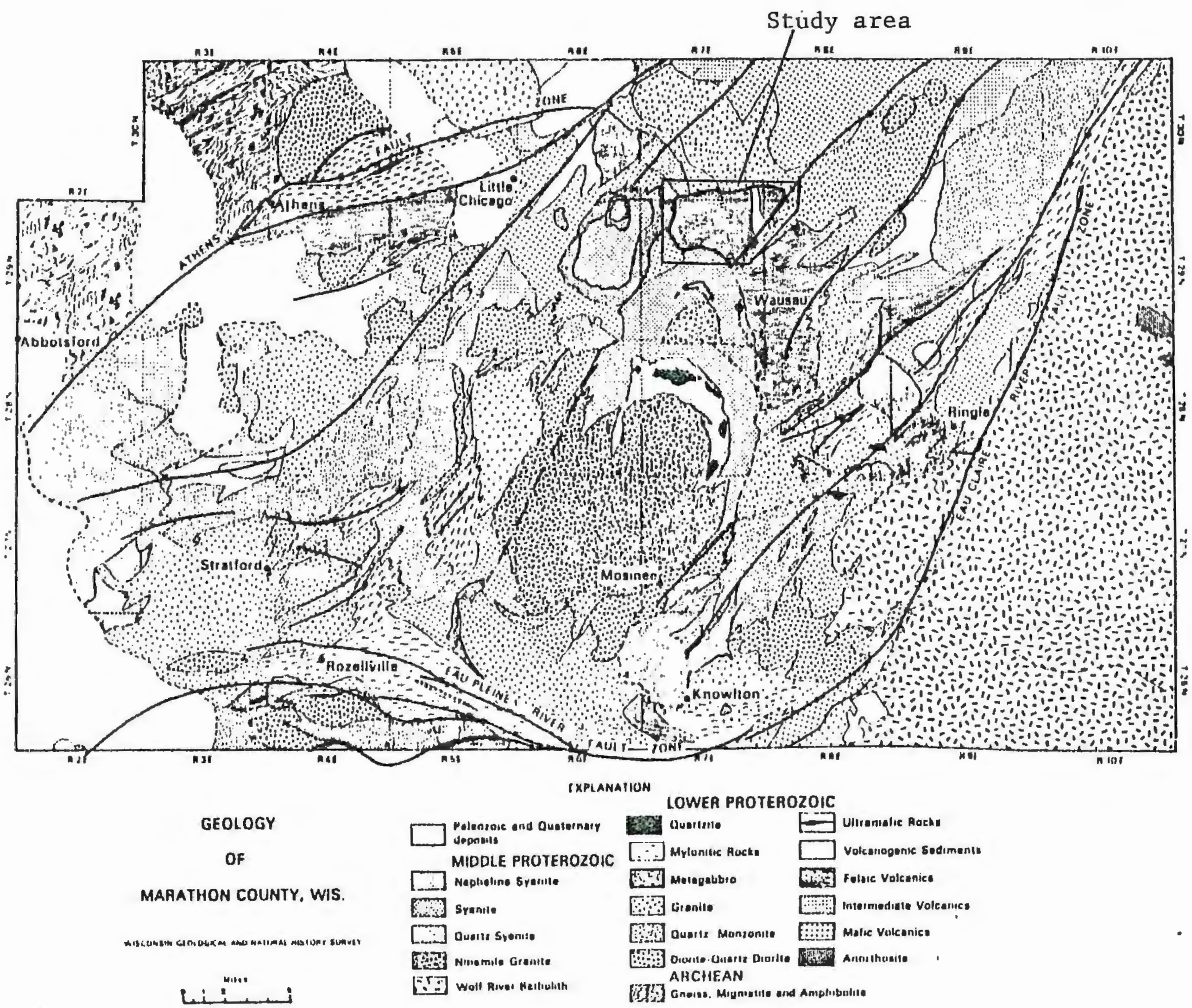

Figure 2: Geologic map of Marathon County (from Laberge and Myers, 1983).

REGIONAL GEOLOGY

Marathon County is located in central Wisconsin near the southern margin of the Superior Upland physiographic province. The Precambrian rocks in central Wisconsin represent the southernmost exposures of rocks in the state comprising the Canadian shield, with the exception of the isolated outliers in southern Wisconsin.

Tectonic Setting

The rocks of central and north-central Wisconsin are dominantly lower Proterozoic volcanics and occur in an east-west trending zone covering roughly 37,000 km^2, with Archean rocks found to the north and south of the zone. These Proterozoic volcanics include pillowed to massive basalts, rhyolite lava flows and pyroclastic rocks interbedded with volcaniclastic sediments. Examples of these volcanic rocks include the Quinnesec Volcanics of Florence and Marinette Counties, the Eau Claire River Volcanics, and the Marathon County Volcanics (Greenberg and Brown, 1983a). Each of these units has yielded a U/Pb age of approximately 1850 to 1900 m.y. The age of these rocks coincides with the Penokean orogeny (Goldich et al., 1961) and for this reason the region has been termed the Penokean Volcanic Belt (PVB) by Greenberg and Brown (1983a). This volcanic terrane is intruded by numerous felsic plutons of similar age which are considered to be related to the orogenic event. The northern boundary of the Penokean Volcanic Belt is placed at the Florence-Niagara fault which separates volcanics considered mainly subaqueous in the south, from the volcanics considered to have continental affinities to the north (Greenberg and Brown, 1983a). The rocks north of the fault have been termed the Northern Penokean Terrane by Greenberg and Brown (1983a), and include the rocks of the Marquette Range Supergroup in northern Wisconsin and the Upper Peninsula of Michigan. The Marquette Range Supergroup includes, from oldest to youngest, the Chocolay Group containing stable shelf-type sedimentary rocks such as quartzite and dolomite, the Menominee Group containing quartzite and iron-formation, and the Baraga Group containing quartzite, slate, iron-formation and volcanic rocks. The volcanics of this sequence have been dated at approximately 1900 m.y., and are apparently older than the volcanic rocks of the Penokean Volcanic Belt (Greenberg and Brown, 1983a).

The juxtaposition of the northern terrane with continental affinities adjacent to the volcanic rocks of central Wisconsin has been explained by means of a plate tectonics model. This model requires the development of a north-dipping subduction zone and an associated island arc-type volcanic belt to the south of a rifted continental margin. A collision between the island arc and the continental margin could be responsible for the Penokean orogeny and the associated deformation and metamorphism (Van Schmus and Bickford, 1981). The location of the subduction zone corresponds in several models (Cambray, 1978, Larue and Sloss, 1980) with the present location of the Niagara fault.

While the Phanerozoic tectonic style (subduction zones) is not unanimously accepted for the early Proterozoic, it is considered to be the best available model.

Stratigraphy

The stratigraphy of central Wisconsin was first described by Weidman (1907). The oldest rocks in the area he termed the Basal Group, which consisted of gneisses and schists found to the south in the Stevens Point area near the southern margin of the exposed Precambrian rocks. These rocks were considered to be of Archean age, possibly Keewatin or Laurentian. Unconformably overlying the gneisses was the Lower Sedimentary Series which he tentatively dated as lower Huronian. This series consisted of the Wausau graywacke, Hamburg slate and the Rib Hill and Powers Bluff quartzites; the stratigraphic relationships of these units was not known. The next youngest sequence was a group of igneous rocks consisting from oldest to youngest of: the Rhyolite Series, the Gabbro-Diorite Series and the Granite-Nepheline Syenite Series. Unconformably overlying these igneous rocks was the Upper Sedimentary Series consisting mainly of contemporaneous conglomerate and quartzite; this unit includes the Marshall Hill conglomerate located in the study area. This unit was considered to be middle Huronian. The Precambrian rocks in central Wisconsin are unconformably overlain by outliers of Cambrian Potsdam sandstone in the south and by Pleistocene glacial sediments over the majority of the area.

The most recent summary of the stratigraphic relationships of central Wisconsin is by LaBerge and Myers (1983) who mapped Marathon County and incorporated geochronology by Van Schmus (1975,1980). Field relations and geochronology placed the Upper Sedimentary Series of Weidman with his Rhyolite Series, rather than younger than the rhyolites as proposed by Weidman.

Further study of the metavolcanic rocks in Marathon County by Laberge, Schulz and Myers (1984) indicates the presence of three volcanic successions, based on variations in metamorphism, deformation and lithologies. The oldest sequence is represented by Proterozoic amphibolites and quartzofeldspathic gneisses, both interpreted by LaBerge, Schulz and Myers (1984) to have been derived from subaqueously-deposited volcanic rocks.

These rocks are characterized by amphibolite facies metamorphism and isoclinal folding with axes trending west-northwest. This sequence is believed to be in contact with Archean qneisses exposed to the south in central Wisconsin. A younger sequence represented by subaqueous basalt and rhyolite unconformably overlies the Archean gneisses and lower Proterozoic amphibolites. This succession has been metamorphosed to greenschist facies and folded about axes plunging to the northeast. The youngest sequence, dated at 1859 m.y. (Van Schmus, 1980), is represented by the rocks in the study area and east of Wausau, and includes felsic volcanics and volcaniclastic sediments. These rocks unconformably overlie the older volcanics and are only mildly deformed about axes plunging 10-20^{o} west. These volcanic and sedimentary rocks have been metamorphosed to lower greenschist facies.

Two periods of igneous intrusion have affected the study area. The oldest event was the emplacement of the Granite Heights Granite. This unit is located directly to the north and northeast of the study area and is in both intrusive and fault contact with the volcanic sequence. LaBerge and Myers (1983) have mapped the igneous body and recognize two variations: an outer rim of quartz monzonite on the southwestern margin, and porphyritic granite representing the major portion of the pluton. This pluton has been dated by Van Schmus et al., (1975) at

1615 $\pm$20 m.y. using the Rb/Sr method. This age is considered to be as much as 15% too young (Van Schmus et al., 1975) and may actually be closer to 1800 m.y. and possibly related to the volcanism. The youngest igneous units are related to the emplacement of the 1500 m.y. Wolf River batholith; they are the Stettin and Wausau syenites located to the west and south, respectively, of the study area. The Stettin syenite is a small zoned pluton consisting of syenite to nepheline syenite and has a broad metasomatized or syenitized zone of volcanics along its eastern margin (LaBerge and Myers, 1983). This altered zone represents the western boundary of the study area. The Wausau syenite is larger than the Stettin pluton and contains several large quartzite xenoliths, the largest of which forms Rib Mountain in Wausau.

Several mafic dikes are present cutting exposures in the study area, but are generally traceable only over short distances. There is a fairly well exposed set of dikes exposed in the 3M quarry south of Brokaw; these dikes may be related to a 1760 m.y. magmatic event in Wisconsin, possibly part of the "andesite suite" described by Mudrey and Myers (1985).

Marathon County was glaciated during the last major ice advance and three separate till sheets are recognized; the Merrill, Cary and Wausau drifts (LaBerge, 1971). The latter unit is considered the oldest and covers the study area. The Wausau drift has been fairly useful in the interpretation of the underlying bedrock as it contains few erratic cobbles, the majority of the cobbles present represent angular fragments of the underlying bedrock brought to the surface by frost action. These angular fragments have been used in part to interpret unexposed areas.

II. GENERAL GEOLOGY

The distribution of volcanogenic rocks in the study area is shown in Plate 1 (in jacket). While the low grade of metamorphism and the relatively undeformed nature of the area has led to the preservation of many original textures, the interpretation of the entire sequence is difficult due to paucity of exposure.

The sequence of rocks represented in the study area is tilted gently to the west, resulting in an east to west younging direction. Many of the volcanic units are laterally discontinuous and relationships between adjacent units is seldom clear. In only two areas, along U.S. Highway 51 and in the 3M quarry, were contacts between units exposed; most of the contacts shown in Plate 1 are interpretations based on float and topography.

The volcanic succession consists of dacitic to rhyodacitic lava flows and pyroclastics, andesitic lava flows, basaltic units and intrusions of several generations. These volcanics are often complexly interbedded with and capped by sedimentary rocks composed primarily of various stages of reworked volcanic detritus. These sedimentary rocks range in grain size from fine-grained siltstones to boulder conglomerates. The dominantly sedimentary units all contain intercalated volcanic units ranging from lava flows to pyroclastic units which were deposited concurrently with the sediments. The interpretation of the geology based on exposures is shown in Plate 1; due to the great variety of rock types present the geology has been divided into three segments in Figure 3. These three segments, from east to west are:

A. The eastermost segment is an undivided, dominantly volcanic sequence comprised of intermediate to felsic lava flows and pyroclastics. The upper portion of this section contains, from oldest to youngest, a fragmental basalt unit, a massive to thinly bedded tuff unit and a dacite lava flow.

B. The central segment contains dominantly sedimentary rocks interbedded with several pyroclastic units and one andesite flow. This sequence consists of, from oldest to youngest, a red conglomeratic sandstone unit, a thinly bedded, tuffaceous siltstone unit, and a greenish-black conglomeratic sandstone unit, which is interbedded with the pyroclastic rocks and an andesite flow.

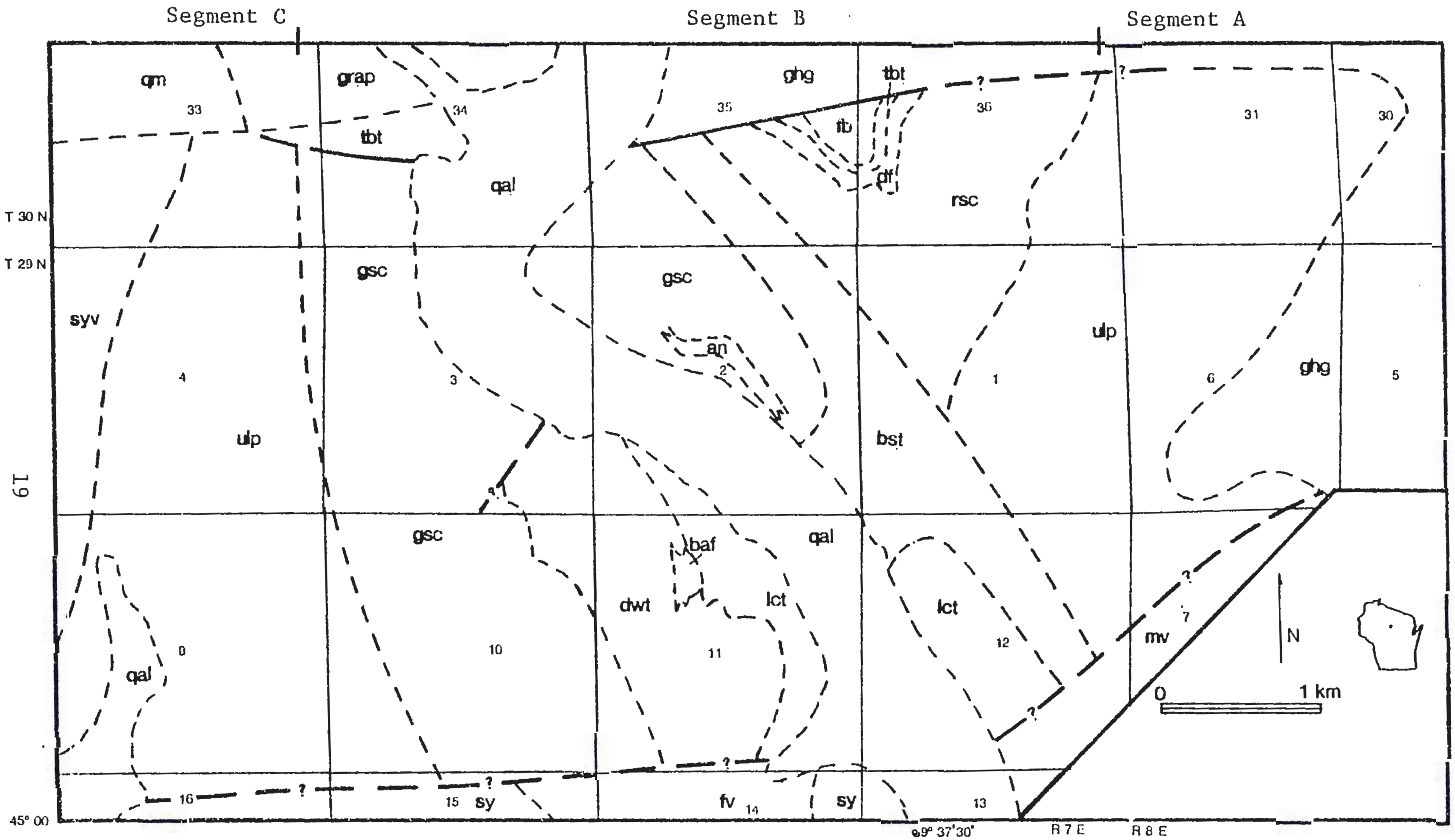

Figure 3: Generalized geologic map of the study area.

Figure 3

Generalized Geologic Map Legend

qal	Quaternary Alluvium
sy	Syenite
syv	Syenitized Volcanics
grap	Aplitic Granite
qm	Quartz Monzonite
ghg	Granite Heights Granite
fv	Felsic Volcanics
mv	Mafic Volcanics
ulp	Undivided Lava Flows and Pyroclastics
gsc	Greenish-black Sandstones and Conglomerates
dwt	Dacite Welded Tuff
baf	Block-and-Ash Flow
lct	Lithic to Crystal-rich Pyroclastics
an	Porphyritic Andesite
bst	Bedded Siltstones and Tuffs
rsc	Red Sandstones and Conglomerates
df	Dacite Flow
tbt	Thinly Bedded Tuff
fb	Fragmental Basalt
— —	Fault
- - -	Contact

Geology of areas surrounding study area after LaBerge and Myers, 1983.

C. The westernmost segment is again dominantly volcanic and very poorly exposed. Units within this section include mainly intermediate to felsic lava flows and pyroclastics.

The inferred stratigraphic column for the study area and the apparent relationships of rock units is shown in Figure 4. Due to poor exposure the thickness of individual units are estimations based upon outcrop location and trigonometry. The relationships between units as shown in Figure 4 are simplifications of the ones seen in the field. The actual relationships between units are very complex due to lithologic variations within each unit, both laterally and vertically in the section. The interfingering of pyroclastic units with the volcanic sandstone units can be seen in several exposures, but must be assumed in areas of only scattered exposure. Detailed descriptions and interpretations of individual units will be included in Chapters III and IV.

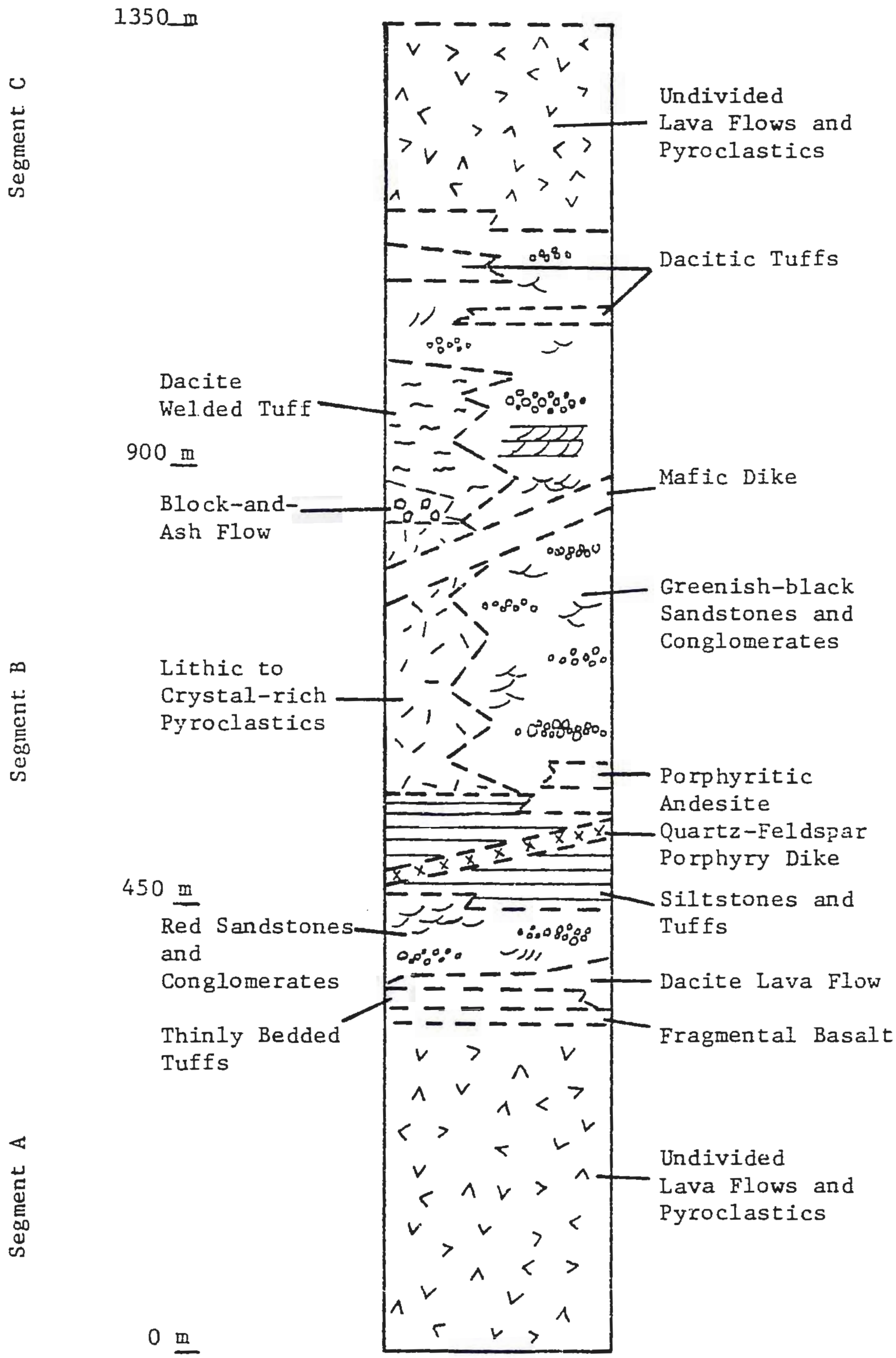

Figure 4: Idealized stratigraphic column for the study area.

III. VOLCANIC AND INTRUSIVE ROCKS

UNIT DESCRIPTIONS AND INTERPRETATIONS

The rocks in the study area are relatively undeformed and the metamorphic grade is low, and therefore many original textures have been preserved. These textures allow some interpretations as to the origin of individual units, but these interpretations are incomplete mainly due to the paucity of exposure. The rock names assigned to these units are based primarily on petrography but the chemical compositions of several samples have been analyzed and will be included in Chapter V. To simplify the terminology, the rock names used do not include the prefix `meta' although an overall lower greenschist facies metamorphism is prevalent. Due to the presence of so many units of varied origin, the following unit descriptions will each conclude with an interpretation in order to more clearly distinguish between the units.

FELSIC and INTERMEDIATE VOLCANICS

Porphyritic Dacite Lava Flows

Exposures of this rock type are found in the NE 1/4, SE 1/4, Sec. 35, T. 30 N., R. 7 E., and there are also many frost-heaved blocks in the northwest-trending stream valley in the NW 1/4, SW 1/4, Sec. 36, T. 30 N, R. 7 E. The exposures of this unit are poor and featureless, so no structural information was obtained from them. Where it could be delimited, this unit is approximately 8-10 m thick. It weathers a white to off-white color and is light gray on a fresh surface.

Thin sections of this rock are fine-grained and are microporphyritic with small euhedral plagioclase phenocrysts (An 25-28) up to 1.5 mm long. These phenocrysts are found as discrete crystals and as glomeroporphyritic clusters which are set in an extremely fine-grained groundmass. Minerals within the groundmass include plagioclase feldspar and 12 to 15% quartz; these minerals are very irregularly shaped and intergrown. According to Williams, Turner and Gilberts' (1984) classification this rock is a dacite as it is composed of greater than 10% quartz and plagioclase is the only feldspar present. The groundmass plagioclase often has a long slender skeletal form (Fig. 5) which may be due to rapid cooling of the lava flow. The groundmass is cut by numerous small-scale quartz and epidote veins along joints and fractures. Plagioclase in both the groundmass and as phenocrysts is partially altered to sericite and chlorite.

In the NE 1/4, NW 1/4, Sec. 4, T. 29 N., R. 7 E., a similar rock type is exposed as an isolated outcrop. This exposure is nonporphyritic, has a similar groundmass, and

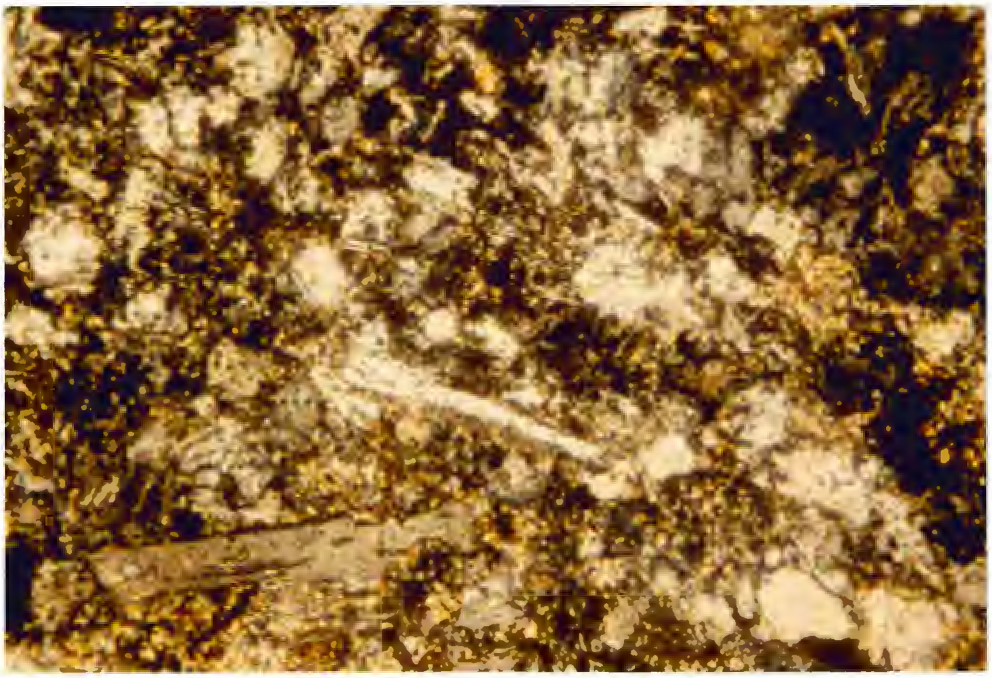

Figure 5: Photomicrograph of porphyritic dacite lava flow. Note elongate skeletal form of some plagioclase crystals. (Crossed nicols, field of view 0.6 mm by 0.4 mm)

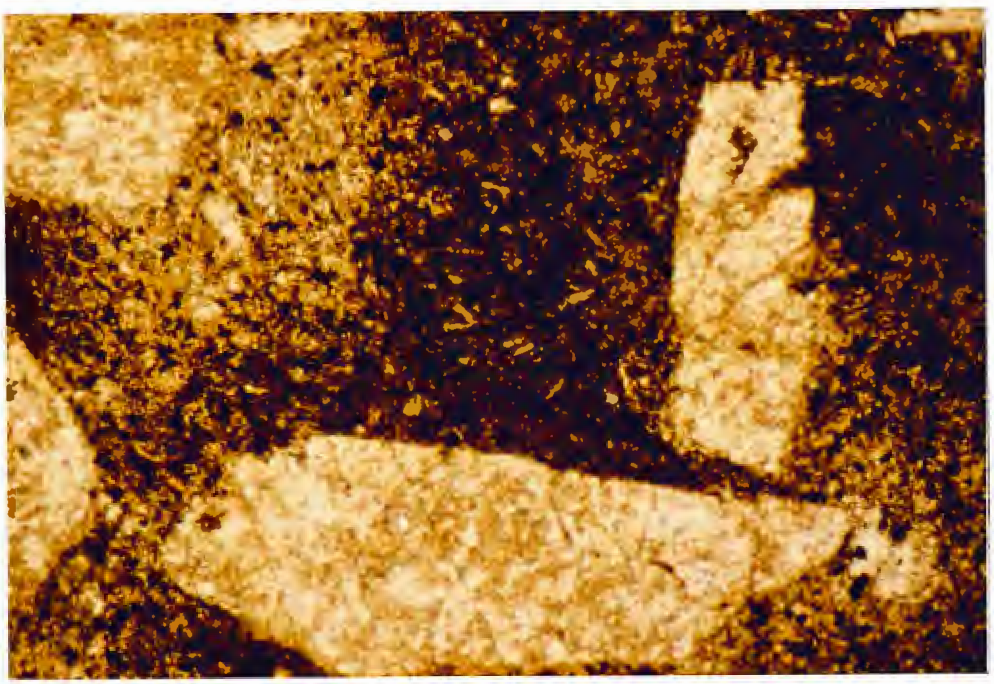

Figure 6: Photomicrograph of porphyritic andesite flow. Note large plagioclase phenocrysts in magnetite-rich groundmass. (One polar, field of view 2 mm by 1.3 mm)

is slightly coarser-grained. This outcrop is extensively jointed and sheared and cut by quartz veins.

Porphyritic Andesite Lava Flows

Two exposures of this unit are located above the railroad tracks on the east side of the Wisconsin River near the center of Sec. 2, T. 29 N., R. 7 E. This unit is quite distinctive, containing 20-25% white plagioclase laths occurring as discrete crystals up to 1 cm long (Fig. 6) and as glomerophryitic clusters larger than 1 cm. These phenocrysts are set in a magnetite-rich fine-grained groundmass containing sericitized plagioclase, calcite, chlorite and minor apatite. Phenocrysts are generally euhedral except where fractured due to small-scale shearing and faulting. They are altered to sericite, calcite, chlorite and to a lesser degree to epidote. The alteration of these phenocrysts indicates albitization has occurred and an An content of An 4-8 is estimated.

This unit is estimated to be 8 to 10 m thick, and is interlayered with a fine-grained pebbly sandstone. Exposures of this rock type are very localized, yet are quite significant in the interpretation of the stratigraphy, for scattered boulders and cobbles of this unit are found as clasts in the conglomeratic sandstones on the west side of the river (Fig. 7).

An isolated exposure of a similar yet distinct type of

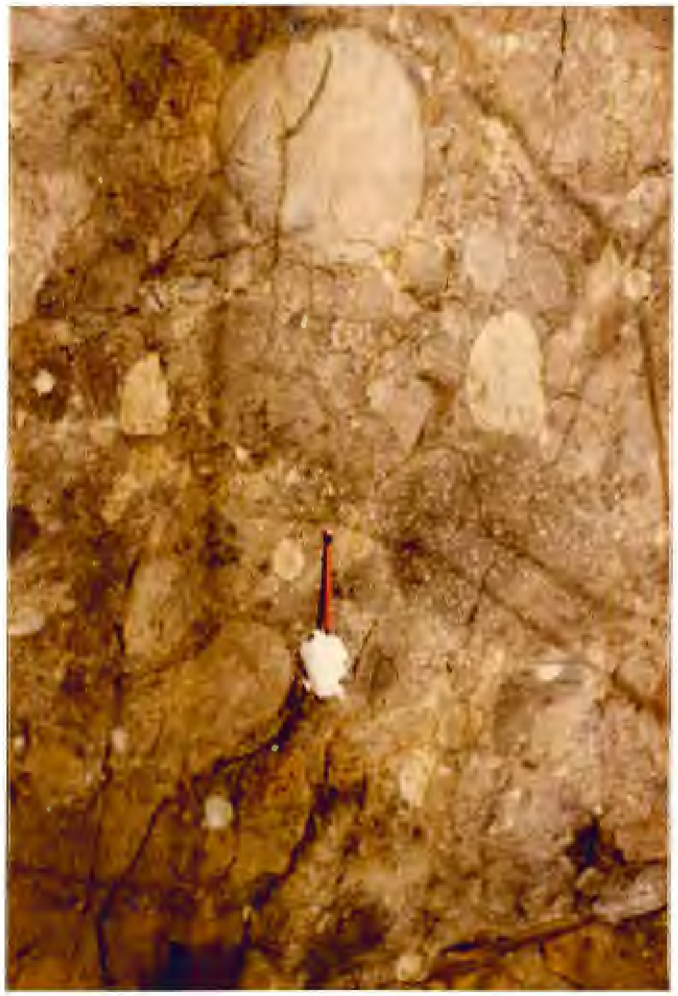

Figure 7: Exposure of conglomerate on west side of the Wisconsin River containing well-rounded boulders of porphyritic andesite.

andesite is located in the SW 1/4, Sec. 31, T. 29 N., R. 8 E., along Lentz Creek. This rock contains less magnetite in the groundmass and is partially sericitized. Plagioclase (An 27-32) phenocrysts (15-20%) are present as single crystals (up to 0.75 mm long) and as larger glomeroporphyritic clusters. These phenocrysts are partially altered to sericite, chlorite, calcite and epidote. The groundmass plagioclase has a pilotaxitic texture. The rock contains approximately 5% amygdules with quartz filling the vesicles.

These two porphyritic andesite flows are located at different stratigraphic levels and are interpreted to be separate unrelated flows.

FELSIC and INTERMEDIATE PYROCLASTIC DEPOSITS

Exposures of units interpreted as having pyroclastic origins are located throughout the study area. These rocks range from coarse pyroclastic breccias to lithic-rich lapilli tuffs and fine-grained laminated ash tuffs. The composition of the clasts in this group of rocks is extremely variable, ranging from crystal-rich to lithic-rich; recrystallized vitric tuffs can also be recognized by preserved textures. The majority of these rocks appear to be unwelded, but two of these units are interpreted as intensely welded tuffs.

Dacite Welded Tuff

Exposures of this rock type were seen at two locations on the west side of the Wisconsin River, west of the Wausau Paper mill in Brokaw and in the 3M quarry. This rock ranges from dark gray to tan on a weathered surface and is reddish brown to grayish brown on a fresh surface. A distinctive feature is the presence of parallel to sub-parallel color bands resembling flow bands; these are very discontinuous, commonly lensing out in less than five centimeters. Aside from the banding this unit is quite homogeneous in appearance with an aphanitic groundmass composed of quartz and feldspar. The extremely fine texture of the groundmass is typical of glassy volcanic rocks that have devitrified. Quartz and calcite veins generally less than 0.25 mm wide are common, often paralleling the color banding.

Two types of phenocrysts are present in this rock; the most abundant type are plagioclase laths (An 25-28), averaging 10-15% of the rock. These phenocrysts are generally less than 2.5 mm long; many appear to be broken, angular and disseminated pieces. These phenocrysts are often oriented roughly parallel to each other and to the color banding. Plagioclase phenocrysts are partially altered to sericite, and calcite replacement is also common. The other phenocryst type is present in small amounts (less than 5%) and exists only as remnant scraps and as psuedomorphs replaced by fine-grained quartz. This phenocryst type is believed to have been an amphibole, probably hornblende; these grains are rimmed by magnetite which is also present along remnant cleavage planes (Fig. 8). Some of the smaller broken fragments which are not replaced by quartz have a dark reddish-brown color which may be due to the oxidation of the hornblende to oxyhornblende.

This unit is estimated to be a minimum of 100 m thick and appears to be quite homogeneous. In the 3M quarry it has a very irregular base where it overlies what may be a block-and-ash flow or lahar, to be described below.

This dacite unit was studied by Asquith (1963) who concluded it was of pyroclastic origin. The present study also supports a pyroclastic origin, based on the widespread occurrence of irregular broken phenocrysts and several examples of extremely flattened pumice fragments draped over phenocrysts (Fig. 9). The extreme flattening of pumice fragments indicates the deposit was intensely welded upon emplacement. The welding and subsequent devitrification have obscured many possibly pyroclastic textures. The presence of the discontinuous banding throughout this unit is problematic; the bands may represent extremely flattened and recrystallized pumice fragments or possibly actual flow banding formed during secondary flow after emplacement of the welded tuff.

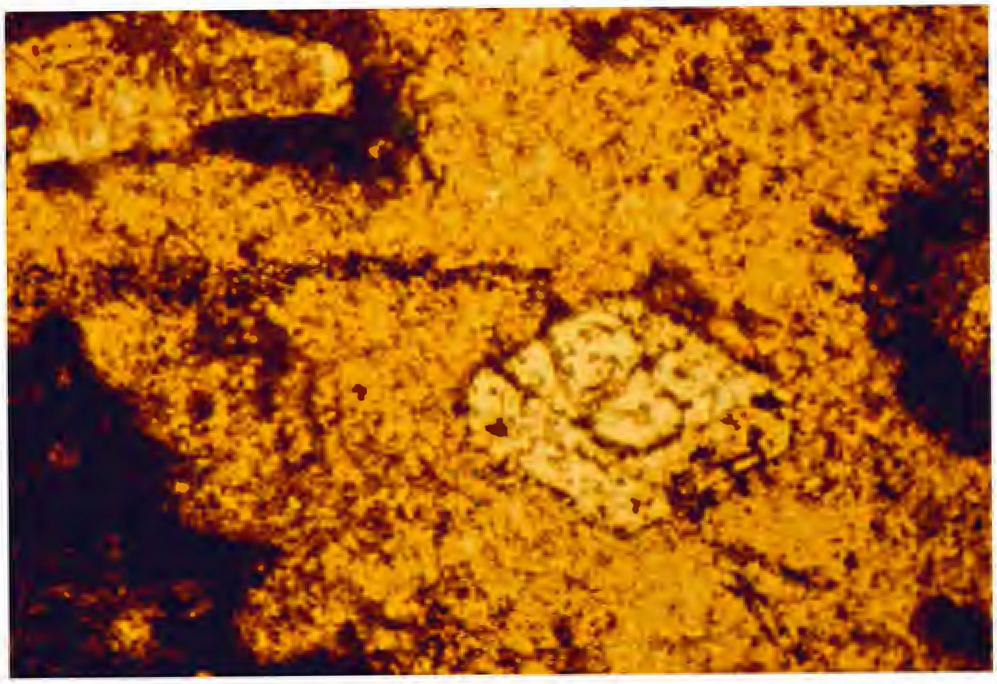

Figure 8: Distinctively shaped hornblende phenocryst from the 3M quarry. Phenocryst has been replaced by quartz; note magnetite concentrated along relict cleavage planes. (One polar, field of view 1.5 mm by 1 mm)

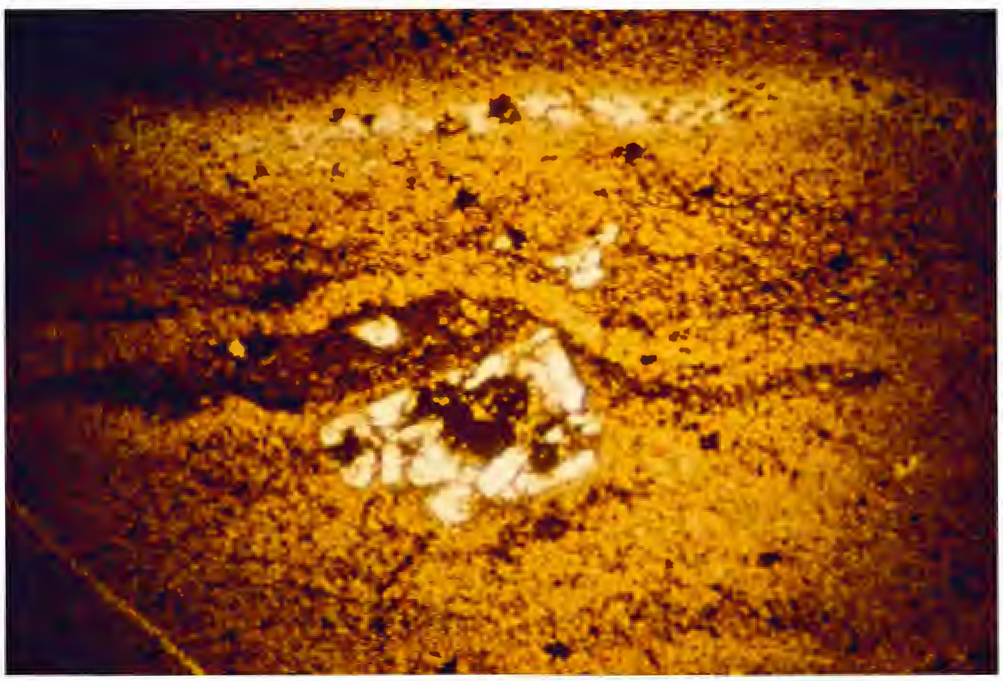

Figure 9: Flattened pumice fragment draped over plagioclase phenocryst in welded tuff from 3M quarry. (One polar, field of view 6 mm by 4 mm)

Block-and-Ash Flow / Lahar

This unit is exposed in the 3M quarry on the west side of the Wisconsin River. This unit is best exposed in the south entrance to the quarry and has an estimated thickness of 15 to 20 m. The groundmass represents 15-20% of the deposit and has been completely sericitized. The alteration of the groundmass has obscured, but not destroyed, the original textures and many ash-size fragments are visible (Fig. 10). These fragments include angular, light colored vesiculated shards, dark nonvesiculated fragments and broken plagioclase phenocrysts. The deposit is poorly sorted and no bedding was visible. Larger, angular to subangular nonvesiculated volcanic fragments ranging from lapilli-sized (50-65%) to blocks (25-30%) up to one meter across represent the remainder of the deposit (Fig. 11). These blocks are quite distinctive, being black to gray in color and contrasting sharply with the light-colored sericitic groundmass. They contain plagioclase laths up to 0.75 mm long, many of which are pink in color due to partial replacement by calcite. Many of these blocks are distinctly flow-banded with plagioclase laths aligned parallel to the flow bands. Both the lapilli-sized clasts and the larger blocks appear to be of the same composition and have the same textures.

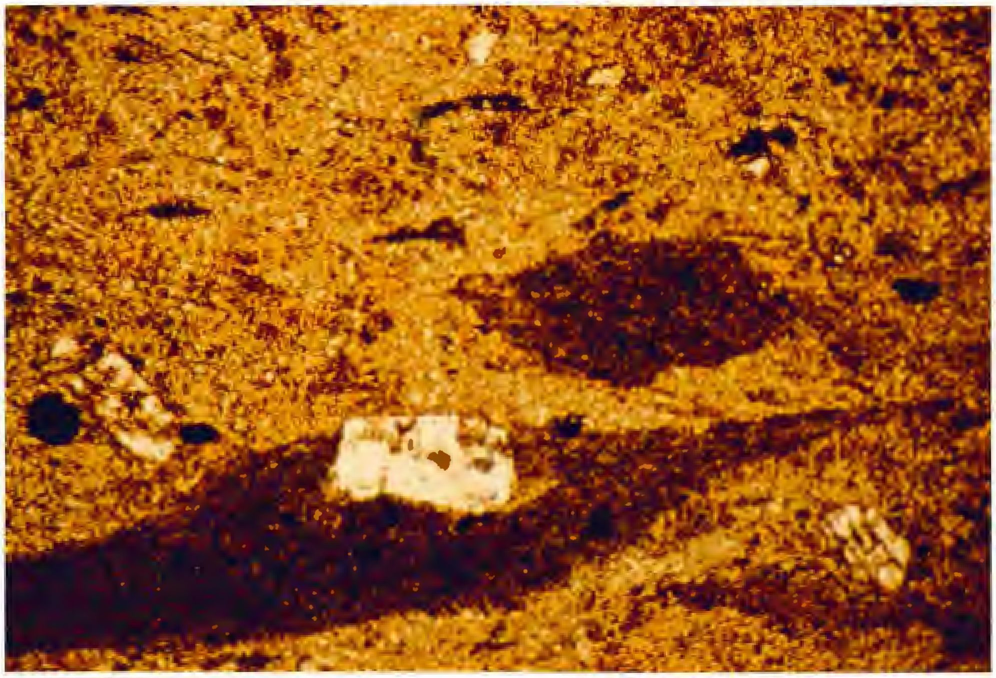

Figure 10: Angular dacite fragments in sericitic groundmass. From exposure of block-and-ash flow unit in the 3M quarry. (One polar, field of view 2.5 mm by 1.5 mm)

Figure 11: Large dacitic blocks in sericitic groundmass. From block-and-ash flow unit in the 3M quarry.

The origin of this deposit is somewhat questionable but it may represent either a block and ash pyroclastic flow or a volcanic debris flow (lahar). The poorly-sorted and unstratified nature of this unit is typical of both lahars and pyroclastic flows, making differentiation difficult. Lahars are more likely to contain more blocks of varying composition and to have more rounded small fragments than a pyroclastic flow (Williams and McBirney, 1979). The angular shape of the clasts and the abundance of blocks of similar lithology suggests that this deposit had its origin as a pyroclastic flow. The flow banded, essentially nonvesiculated texture of many of the large blocks may indicate derivation from a dome or lava flow that was fragmented by explosions initiating the break-up and the addition of juvenile material due to these explosions (Pelean type) (Williams and McBirney, 1979). An alternative interpretation has been suggested by Morton (1986), who indicates this unit may represent a lag fall deposit related to the overlying dacite welded tuff.

Thinly Bedded to Massive Tuffs

Exposures of this unit are found in two locations on the north edge of the study area; in the NE 1/4, SE 1/4, Sec. 35, T. 30 N., R. 7 E., and along U. S. Highway 51 in the NE 1/4, SW 1/4, Sec. 34, T. 30 N., R. 7 E. These rocks range in color from a salmon-pink to off-white to dark green. They are characteristically aphanitic to very fine-grained. The exposure in Sec. 35 is a salmon-pink massive rock containing small amounts of disseminated pyrite. No bedding was seen in this exposure, but abundant float nearby suggests that this unit also contains a thinly bedded facies. Several angular, lapilli-sized pumice fragments, with 5-10% vesicles, were recognized in samples from this exposure and small structures thought to be highly altered glass shards were seen in thin section. The exposure in Sec. 34 is similar, but is bedded with pink, white and greenish-black bands of various thickness alternating through most of the exposure (Fig. 12). Mineralogically these rocks consist mainly of sericite colored by small amounts of hematite; the dark green bands consist of chlorite with small amounts of epidote. Angular unit quartz grains less than 0.25 mm across are scattered throughout this rock.

The recognition of angular pumice fragments and possible shard structures indicates a pyroclastic origin for these rocks. The complete alteration of the groundmass to fine-grained sericite (75-80%) and chlorite (20-25%) has obscured many of the fine details. These rocks may represent air fall deposits formed by the settling of fine ash following an eruption. Such thinly bedded deposits are also associated with tuff rings and cones formed during hydrovolcanic eruptions of mafic

Figure 12: Exposure of fine-grained thinly bedded tuff along U.S. Highway 51. Outcrop is cut by numerous small-scale faults.

lavas. The presence of small, angular quartz grains may indicate either an eruption of felsic composition or addition of unconsolidated detrital material during the explosive hydrovolcanic eruption of a mafic magma.

The two exposures described are similar in mineralogy, texture and appearance and are assumed to represent the same unit. Field evidence suggests the exposure along U.S. Highway 51 has been faulted into its present position.

Ash and Lapilli Tuffs

In the SW 1/4, Sec. 3, T. 29 N., R. 7 E., there is an approximately 5-6 m thick pyroclastic unit exposed at the end of the southbound ramp onto U.S. Highway 51. This unit strikes SE and is also exposed on the east side of the highway. It is interbedded with a sequence of volcanic sandstones and appears to have been partially eroded, as the upper contact is very irregular with up to 15 cm of relief, and a conglomerate unit with well rounded boulders unconformably overlies it. These exposures have a dark reddish color and are massive; no bedding or layering was seen.

This rock is composed of 25-30% broken, angular plagioclase (An 18-24), some with cores altered to sericite and calcite, and 15-25% lithic fragments of various compositions. Lithic fragments include porphyritic mafic to intermediate volcanics (15-20%) and plutonic fragments (2-5%) of tonalitic composition. Clast sizes average less than 2 mm, though some larger lapilli-sized fragments up to 5 mm are present. The groundmass (25-30%) consists of a very fine-grained mixture of quartz and feldspar and may represent devitrified ash. This unit can be classified as a crystal-lithic tuff of approximately dacitic composition, and it appears to be unwelded.

Exposures in the NW 1/4, Sec. 12, T. 29 N., R. 7 E., on the east side of the Wisconsin River and at the entrance to the 3M quarry in the NW 1/4, Sec. 11, range from lithic-rich lapilli tuffs to fine-grained crystal tuffs. Exposure is poor on the east side of the river but large angular frost-heaved blocks consisting of coarse lapilli tuffs are present (Fig. 13). These tuffs appear massive and contain large angular fragments (5-10%) more than 5 cm across, although the clasts generally average about 2-4 mm. This portion of the unit is rich in intermediate porphyritic volcanic fragments (40-50%) and (5-10%) magnetite-rich porphyritic to vesiculated mafic fragments. Many of the smaller fragments (10-15%) in the interstices are quite angular and appear to be vesiculated shards. On the west side of the Wisconsin River in Sec. 11, the pyroclastics appear to be more crystal-rich, containing fewer varieties of clasts and more juvenile

Figure 13: Frost-heaved block of coarse lapilli-tuff from east side of Wisconsin River.

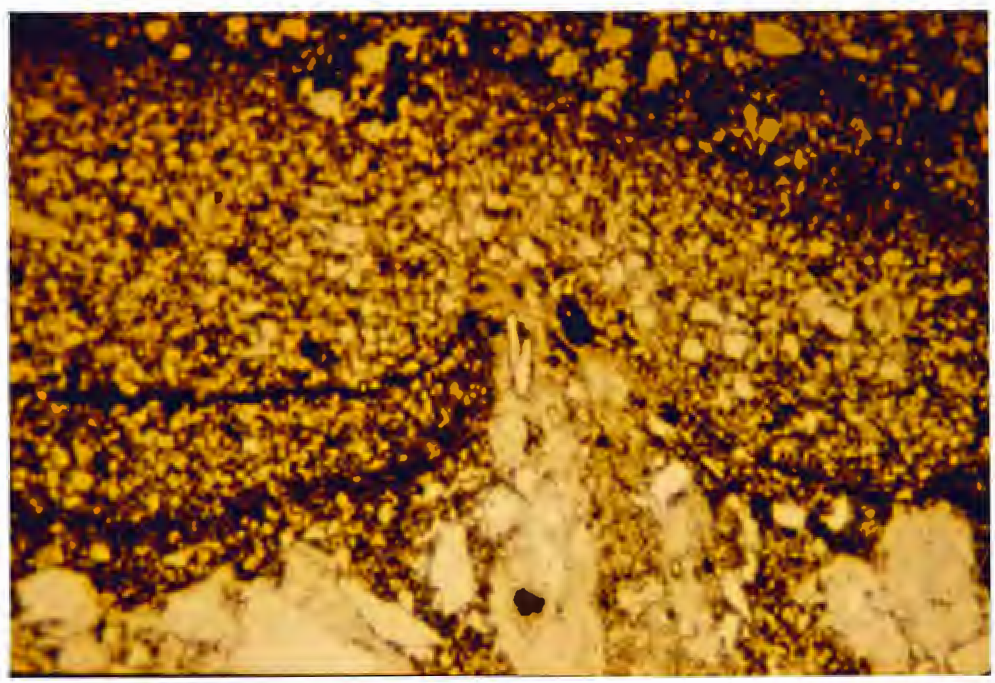

Figure 14: Thin airfall tuff layer draped over lithic fragment. Note the symmetrical grading of this bed. (One polar, field of view 4 mm by 3 mm)

fragments. These rocks range from crystal tuffs to recrystallized vitric crystal tuffs with scattered lapilli-sized lithics. They are reddish-brown in color and are generally massive, though some fine-bedded ash layers are present. These ash layers drape over protruding fragments and are often normally graded, though one thin ash bed (5 mm thick) appears symmetrically graded, going from fine to coarse and back to fine (Fig. 14). Ash beds that drape over the underlying irregularities are commonly found in units deposited by airfall (Fisher and Schmincke, 1984). Graded bedding can develop in airfall deposits due to variations in eruption intensity and due to sorting of ash caused by air turbulence (Williams and McBirney, 1979).

Minor Pyroclastic Units

A complexly jointed and sheared exposure along U.S. Highway 51 in the SE 1/4 Sec. 10, T. 29 N., R. 7 E., contains both a porphyritic dacite lava flow and a pyroclastic flow deposit. The pyroclastic rock is brown to buff in color and is somewhat mottled. In thin section it is interpreted as an unwelded recrystallized vitric-crystal tuff. Average fragment size is 1-2 mm though some lapilli-sized clasts are present. Plagioclase (An 25-28) as large fractured and broken crystals up to 3 mm long is the most abundant mineral present, comprising 20-25% of the rock. The remainder of the rock is groundmass composed of fine-grained quartz, feldspar and sericite. This groundmass exhibits well-preserved pyroclastic textures such as recrystallized cuspate and platy bubble wall shards (Fig. 15), and more elongate pumice shards (Fig. 16). These shards are undeformed and are easily recognized in plane polarized light. Shards of this type are formed by the rapid vesiculation of a felsic magma during subaerial eruption. The cuspate bubble wall shards tend to form when magma temperatures exceed 850°C, and the elongate pumice shards may be more common below 850°C when the magma is more viscous (Fisher and Schmincke, 1984).

A small sheared exposure of recrystallized and spherulitic vitric-crystal tuff occurs on North Troy Street, Wausau, in the NE 1/4, Sec. 12, T. 29 N., R. 7 E. Thin sections of this rock show faint and possibly welded shard structures, but recrystallization and shearing have obscured these textures.

Exposures in the SE 1/4, Sec. 6, T. 29 N., R. 8 E., range from fine ash to lapilli tuff. These tuffs are crystal-lithic tuffs containing abundant broken quartz and plagioclase (An 19-24). Lithic components include porphyritic intermediate and mafic varieties and massive non-porphyritic felsites. The groundmass contains angular fragments of plagioclase crystals and lithics in a fine-grained sericitized matrix.

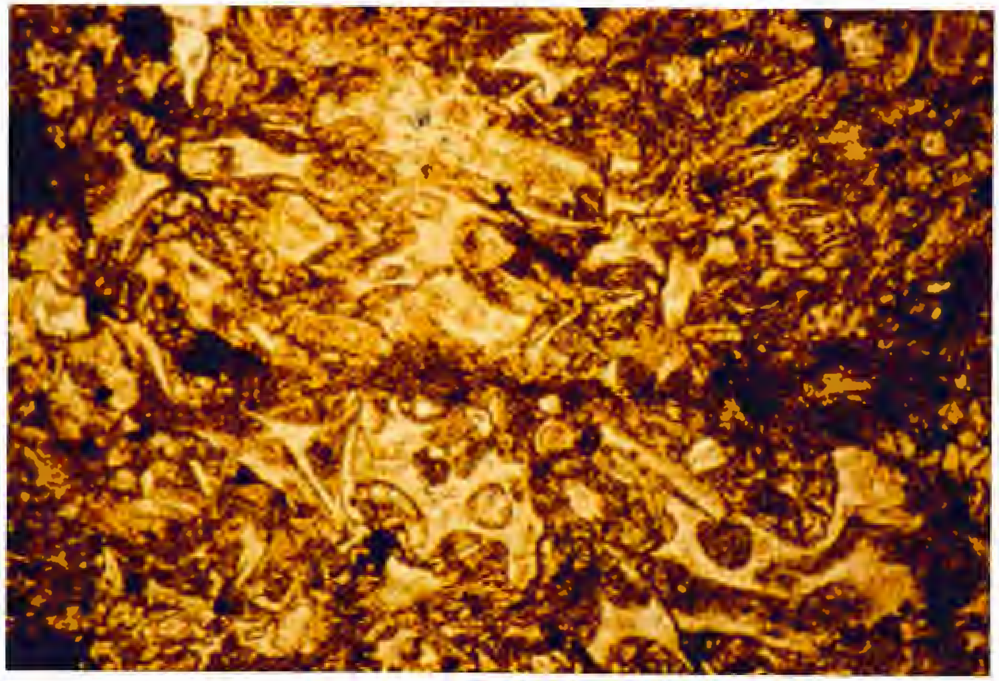

Figure 15: Well-preserved cuspate and platy bubble-wall shards. From exposure along U.S. Highway 51. (One polar, field of view 2.5 mm by 1.5 mm)

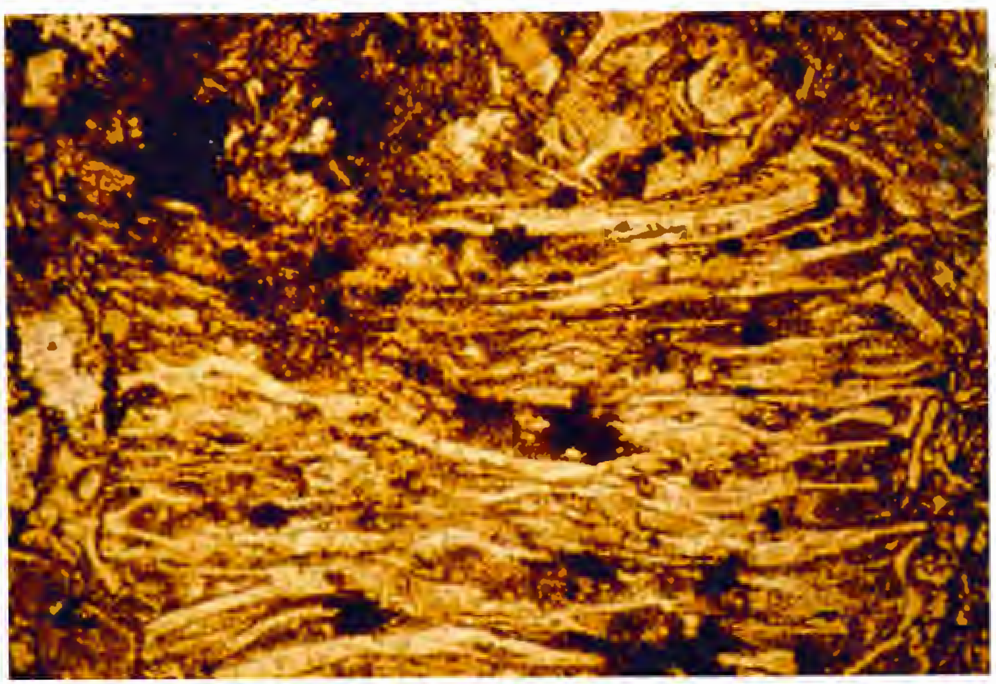

Figure 16: Large well-preserved pumice shard with smaller bubble-wall shards. From exposure along U.S. Highway 51. (One polar, field of view 2.5 mm by 1.5 mm)

MAFIC VOLCANICS

Basalt

Four isolated outcrops of basalt occur in the northern portion of the study area. The basalt in the NW 1/4, SE 1/4, Sec. 35, T. 30 N., R. 7 E., is dark red in color, aphanitic and moderately amygdaloidal (5-10%). This unit has been extensively silicified and thin sections show small (1 mm wide) quartz veins and amygdules in a dark hematite-rich groundmass. The quartz veins are typically white in color, but some portions are bright red; these veins also contain coatings of specular hematite. Epidote, chlorite and small amounts of actinolite are present in veins and scattered in the groundmass. Small, altered plagioclase laths (30-40%) are the major mineral component of this rock but they are masked by the silicification and the opaques.

The basalt in the NE 1/4, SE 1/4, Sec. 35, T. 30 N., R. 7 E., is a dark brown, aphanitic, massive to amygdaloidal basalt that has been silicified and jointed. Thin-sections of this basalt show distinctive textures, consisting of numerous angular and blocky aphanitic clasts (Fig. 17). Many have curved edges, giving a shard-like appearance; this texture is possibly due to fracture across vesicles. The groundmass for these fragments represents 10-15% of the rock and is mainly fine-grained

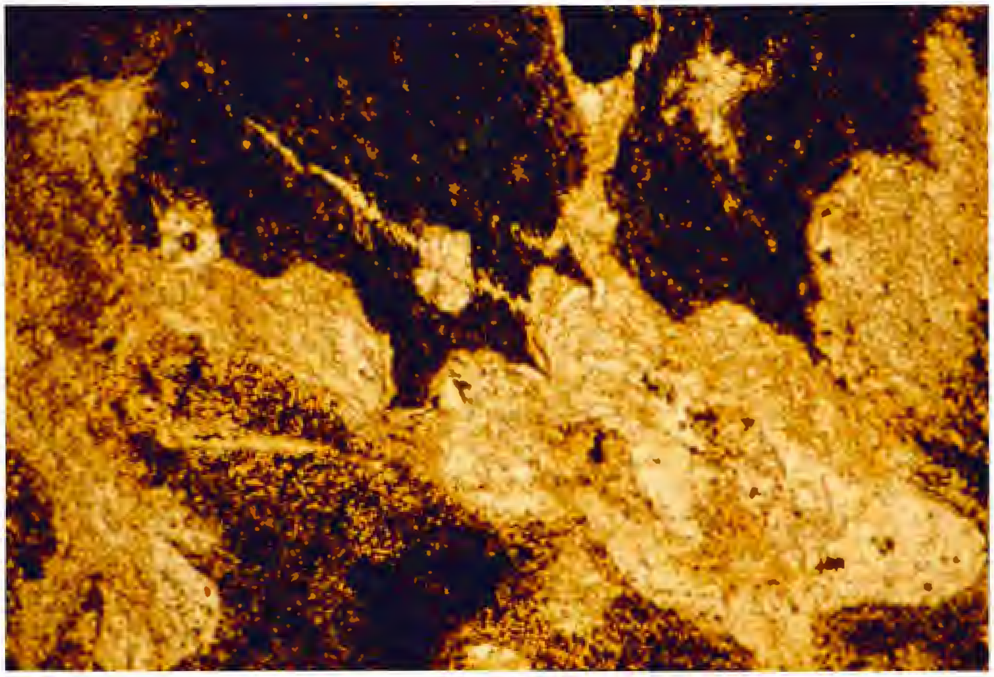

Figure 17: Angular mafic shards in light-colored silicified groundmass. (One polar, field of view 2 mm by 1.3 mm)

quartz with small amounts of sericite. The origin of this unit is uncertain; blocky, angular, slightly vesiculated shards are common in hydroclastic deposits of shallow water or subaerial environments. These deposits form when magma or lava flows come in contact with shallow water or groundwater, resulting in quenching and phreatomagmatic explosions which result in further fragmentation of the quenched magma. Blocky mafic shards have been commonly associated with deposits of tuff rings, maars and littoral cones formed due to phreatomagmatic eruptions (Fisher and Schmincke, 1984). Exposures are too poor in this area to allow precise interpretation; the lack of any recognized pillow structures may indicate deposition in a shallow water or subaerial environment.

The basalt in the NE 1/4, SE 1/4, Sec. 36, T. 30 N., R. 8 E., is dark greenish-black and massive in outcrop, with no amygdules seen. Thin sections of this rock show textures very similar to those just described. This outcrop contains mafic clasts in a silicified groundmass (5-10%), but contains abundant actinolite and epidote replacing the mafic minerals. This rock may have formed in a manner similar to the one just described, and it may be part of the same unit.

The basalt in the NW 1/4, SE 1/4, Sec. 33, T. 30 N., R. 7 E., is a brown-weathering, aphanitic, sheared and fractured rock cut by many quartz veins. Thin sections of this rock consist dominantly of fine-grained actinolite (30-35%), (25-30%) plagioclase (An 38), (5-10%) chlorite and (2-5%) epidote. This rock has been recrystallized and no original textures were recognized.

INTRUSIVE ROCKS

Quartz-Feldspar Porphyry Dike

This unit occurs in one location in the study area, along County W in the SW 1/4, SE 1/4, Sec. 1, T. 29 N., R. 7 E. This rock is poorly exposed and is interpreted as a dike cross-cutting the siltstones. It is a light yellow to buff color and is less resistant than the surrounding siltstones. It contains large subhedral quartz crystals up to 3.5 mm across; some of these are embayed and contain inclusions of the groundmass. Plagioclase crystals (An 5) that have been partially altered to sericite and calcite, are present as porphyritic to glomeroporphyritc phenocrysts up to 4 mm long are also quite abundant. The groundmass consists of a fine-grained mixture of quartz, feldspar and sericite.

Dacite Dike

This dike occurs as a small finger-like intrusion into tuffaceous sediments in the exposure on the southbound ramp onto U.S. Highway 51 (Fig. 18). This rock is

Figure 18: Small finger-like dacitic intrusion into tuffaceous sediments on the west side of U.S. Highway 51.

Figure 19: Photo of meter-wide sill in the 3M quarry.

porphyritic to glomeroporphyritic with plagioclase phenocrysts (An 25) up to 2 mm long. The groundmass consists of a fine-grained mixture of quartz, feldspar and minute magnetite. This dike is similar in mineralogy and color to several of the volcanic rocks seen nearby and may be related.

Mafic Dikes

Mafic dikes occur as isolated outcrops in the central portion of the study area. The best exposures occur in the 3M quarry in the NW 1/4, of Sec. 11; others occur in the SW 1/4, Sec. 3, T. 29 N., R. 7 E., and in the NE 1/4, Sec. 3, T. 29 N., R. 7 E.

The 3M quarry contains several large dikes that branch into smaller dikes and a small sill. These dikes weather a rusty brown color and break apart readily. The rusty color is due to the weathering of disseminated pyrite. A sample taken from the one meter wide sill (Fig. 19) at the entrance to the quarry is porphyritic, containing large (7 mm) pink plagioclase crystals. These phenocrysts are anhedral with unusual rounded margins, due to resorption (Fig. 20); they are also quite altered. Phenocrysts of pyroxene up to 3 mm across are completely replaced by actinolite and chlorite (Fig. 21). Magnetite is present as disseminated anhedral blebs up to 4 mm across but is more commonly seen as fine-grained rims surrounding other

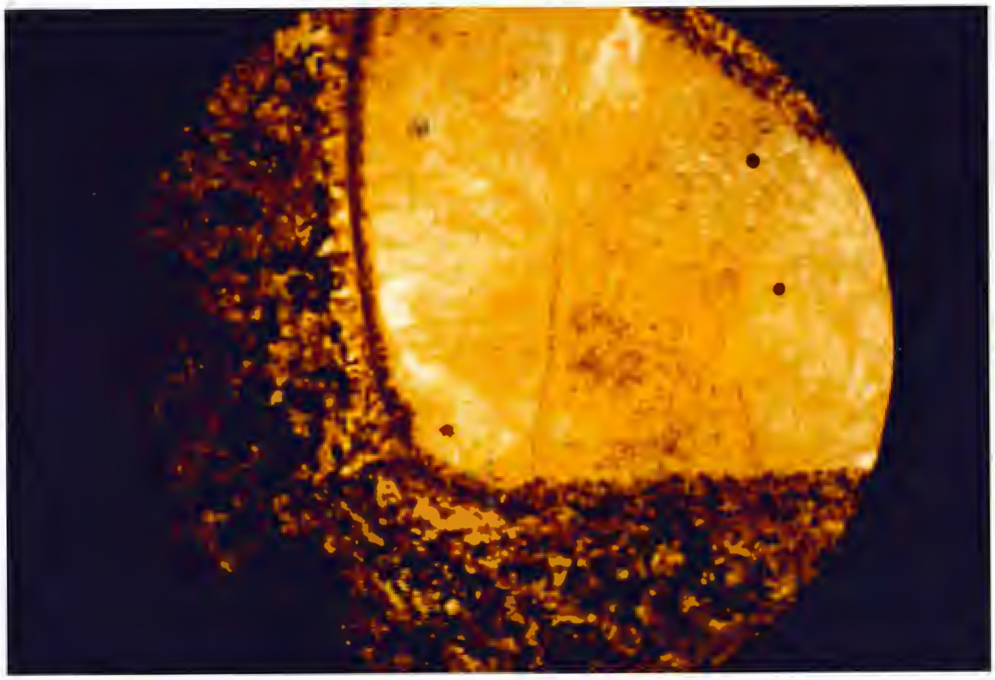

Figure 20: Large resorbed plagioclase phenocryst in mafic dike. From the 3M quarry. (One polar, field of view 4.5 mm)

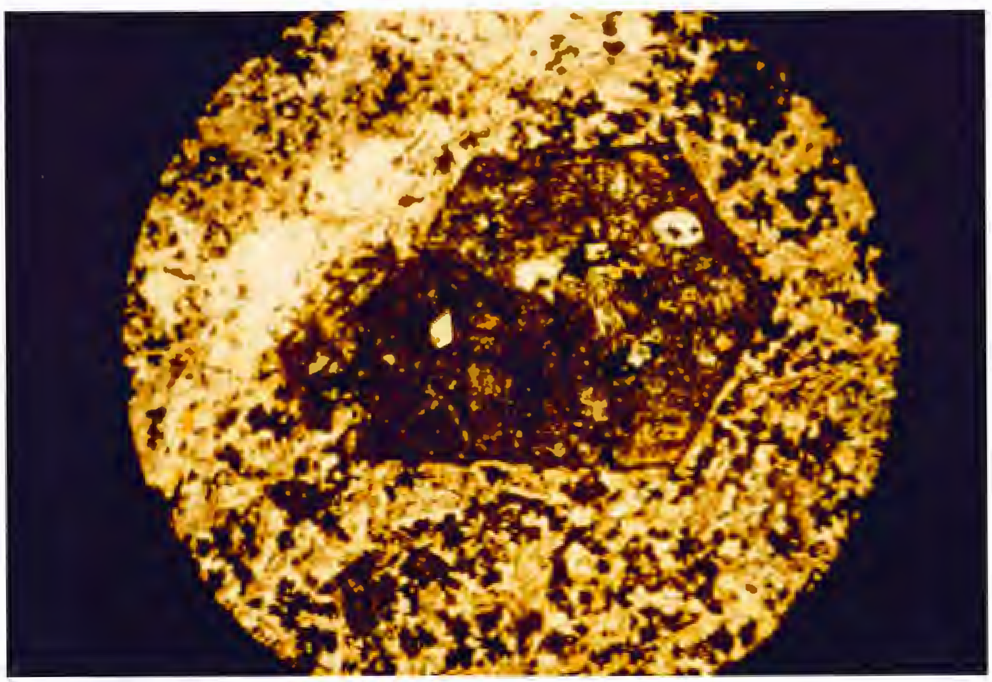

Figure 21: Euhedral pyroxene phenocryst, replaced by actinolite and chlorite. From mafic dike in the 3M quarry. (One polar, field of view 4.5 mm)

phenocrysts. The groundmass consists of a fine-grained felty mixture of sericitized plagioclase, actinolite replacing pyroxenes, chlorite, calcite, magnetite, pyrite and apatite.

A dike approximately two meters wide in the SW 1/4, Sec. 3, is poorly exposed in a low rubbly outcrop along Highway 51. This dike is a dark greenish-black color and cuts dark greenish-black volcanic sandstone making it difficult to see. It contains small 0.75 mm phenocrysts of subhedral to euhedral plagioclase. Mafic minerals have been completely replaced, mainly by fine-grained chlorite and minor actinolite. The groundmass consists of chlorite, magnetite and microlites of plagioclase arranged in a pilotaxitic fabric. Calcite and quartz veins are present along the margins of the dike.

The 2-meter wide dike in the NW 1/4, Sec. 3, strikes nearly east-west and is well exposed. It is greenish-black in color and also cuts the dark greenish-black sandstones and is difficult to see. This dike is composed of small unoriented plagioclase phenocrysts that are intensely altered to sericite and calcite. Epidote, chlorite and minor magnetite are the only mafic minerals present. The epidote occurs as scattered grains and as large spherules up to 3 cm in diameter.

IV. SEDIMENTARY ROCKS

Greenish-black Volcanic Sandstones and Conglomerates

This unit is located in the north-northwest portion of the study area and is one of the best exposed units. It has a minimum thickness of 300 meters and is composed primarily of volcanic fragments and minor quartzite and plutonic rock fragments that have undergone various stages of reworking. The volcanic sandstones range from gray to greenish-black in color, depending on the amounts of chlorite and epidote present. Bedding is also variable, ranging from 2 to 3m thick massive beds to medium bedded (5 to 20 cm thick) parallel beds, and cross-beds are present throughout the unit. Bedding is relatively discontinuous and most beds cannot be traced the length of the exposure before lensing out or being intersected by an overlying channel.

The clasts of the conglomerates that are interbedded with the volcanic sandstones are well-rounded to subrounded and range in size from pebbles to boulders as large as 35 cm in diameter. The majority of these clasts are intermediate to felsic volcanics, with lesser amounts of mafic volcanic fragments. Clasts of tonalitic to granitic composition and quartzite clasts are typically small, rounded pebbles less than 4 cm in diameter and are relatively rare (less than 2 to 3% of the clasts). Conglomerate beds range in thickness from single pebble layers to massive beds 1 to 2 meters thick. They appear to have been deposited in channels and are generally truncated by the overlying bed resulting in lense-like cross-sections. The width of these channels is difficult to measure due to lack of exposure, but some are more than 10 meters wide. These conglomerates are clast-supported and the matrix between the clasts is similar to the volcanic sandstone previously described.

Petrography

The framework components of these sandstones and conglomerates are variable suggesting a complex source area. These sandstones range from poorly to well sorted. The average grain size is approximately 1 mm but there is a wide variation in size from fine-grained (0.25 mm) to coarse sandstone. Sand-sized grains range from well-rounded to angular; and grain shapes can vary greatly in a single sample and in different beds in the unit. The detrital modes of twelve samples were determined by point-counting; the results of these analyses are shown in Table 1. The volcanic grains range in shape from well-rounded to angular, suggesting varied transport distances. The compositions of the volcanic fragments are

SAMPLE #	W84-7	W84-10	W84-125	W84-92	W84-74	W84-73	W84-75	W84-56	W84-128	84-WI-1A	84-WI-1B	84-WI-1C
Undulose Quartz	10.0	10.8	13.6	1.0	23.6	22.2	22.5	27.9	23.0	16.0	18.7	3.2
Polycrystalline Quartz	1.8	3.0	1.3	-	6.0	4.7	0.2	0.6	1.8	3.3	1.4	-
Plagioclase	14.0	12.9	10.0	5.7	3.6	11.2	12.3	30.1	14.2	10.5	11.3	21.2
F VRF	6.7	4.6	3.6	5.4	16.0	3.5	3.6	4.1	11.1	4.7	2.7	2.7
F-IVRF	45.8	33.0	32.1	58.8	21.1	31.0	35.1	-	12.1	28.3	45.5	38.7
M VRF	2.0	18.5	2.6	12.2	6.8	7.5	5.9	-	4.1	6.0	5.4	9.9
Plutonic RF	1.5	8.3	1.5	-	15.0	5.8	2.9	-	1.9	1.2	3.5	-
Magnetite	2.2	4.3	1.8	4.4	0.5	0.8	3.5	5.6	2.3	5.7	4.4	9.3
Epidote	5.5	2.0	17.7	2.2	0.4	-	1.3	0.3	12.4	6.7	1.1	1.5
Calcite	-	-	-	-	-	-	1.7	6.5	-	-	-	-
Chlorite	10.5	2.5	10.3	-	3.5	0.5	2.1	13.5	1.9	9.4	2.5	2.9
Sericite Matrix	-	-	-	-	3.5	12.6	9.2	11.2	15.2	-	3.5	10.6
Chert Cement	-	-	5.5	10.3	1.8	-	-	-	-	8.2	-	-
Grain Size (Ave.)	0.5mm	1-2mm	0.5-0.7mm	0.5-6mm	0.5-6mm	0.5-4mm	0.5-1	0.25mm	0.5-4mm	1mm	1.5mm	0.5-1mm
Roundness	subrnd-ang	rnd-subang	rnd-subang	rnd-ang	rnd-subang	rnd-subang	rnd-subang	subrnd-ang	rnd-ang	subrnd ang	subang-rnd	subrnd-ang
Sorting	mod	mod	mod	poor	poor	poor	mod	well	poor	well	mod-well	mod-well

Table 1: Modal analyses of greenish-black volcanic sandstones.

dominantly felsic to intermediate with textures including massive aphanitic, plagioclase- porphyritic, flow banded, holocrystalline and vesicular. Many of these grains are highly sericitized. Fragments of definitely felsic composition are less abundant and are commonly recognized by their quartz phenocrysts and recrystallized glassy fragments looking much like chert. Dark, mafic volcanic fragments are typically magnetite-rich and range from porphyritic to pilotaxitic and vesicular.

<u>Operational Definitions of Components</u>

Undulose Quartz-	The majority of the unit quartz grains are volcanic; due to deformation most grains exhibit undulatory extinction.
Polycrystalline-Quartz	Sedimentary quartz grains consisting of two or more units. Includes jasper, recrystallized chert, and quartzite; some grains may represent recrystallized phenocrysts.
Plagioclase-	Twinned and untwinned crystal fragments altered to various degrees to calcite, sericite and chlorite.
F VRF-	Felsic Volcanic Rock Fragments. Light-colored grains, often resembling chert. May be quartz-porphyritic, spherulitic or flow-banded.

F-IVRF-	Felsic to Intermediate Volcanic Rock Fragments. Generally of indeterminate composition and slightly darker in color than F VRF, some are extensively sericitized. Plagioclase phenocrysts are present in most.
MVRF-	Mafic Volcanic Rock Fragments. Dark, magnetite-rich fragments, may be pilotaxitic, vesicular and aphanitic.
Plutonic RF-	Dominantly tonalitic to granitic in composition; grains are polycrystalline consisting of quartz and plagioclase.
Magnetite-	Anhedral to euhedral detrital grains.
Epidote-	Found as grains replacing plagioclase and volcanic rock fragments.
Chlorite-	Chlorite is present as cement between grains; some may represent highly altered plagioclase and volcanic rock fragments.
Chert Cement-	Rims of fine-grained quartz on quartz grains and felsic volcanic rock fragments; may be found alone or with chlorite and sericite.
Sericite Matrix-	Fine-grained sericite between grains and in patches. Some may be highly

altered F-IVRF and plagioclase.

Calcite- Found replacing plagioclase and as a cement in association with plagioclase.

Classification

These sandstones are lithic arenites according to Dott's (1964) classification and are volcanic arenites using Folk's (1968) breakdown of lithic sandstones (Fig. 22). The classifications by Dott and Folk allow comparison of maturity to other sandstones but do little to closely define the type of source area being eroded at the time these sandstones were deposited. To further define the tectonic environment these sandstones have been classified after Dickinson et al., (1983) (Fig. 23). This classification is a revised version of Dickinson and Suczek's (1979) classification for Phanerozoic sandstones and is based on plate tectonic theory. The tectonic style of the Precambrian is poorly understood; for this study a modern plate tectonics style will be assumed to allow comparison of these sandstones with younger sediments. The classification by Dickinson et al., (1983) utilizes two ternary diagrams; a QFL and a QmFLt diagram based on modal percentage of end members. The following explanation is from Dickinson et al., (1983):

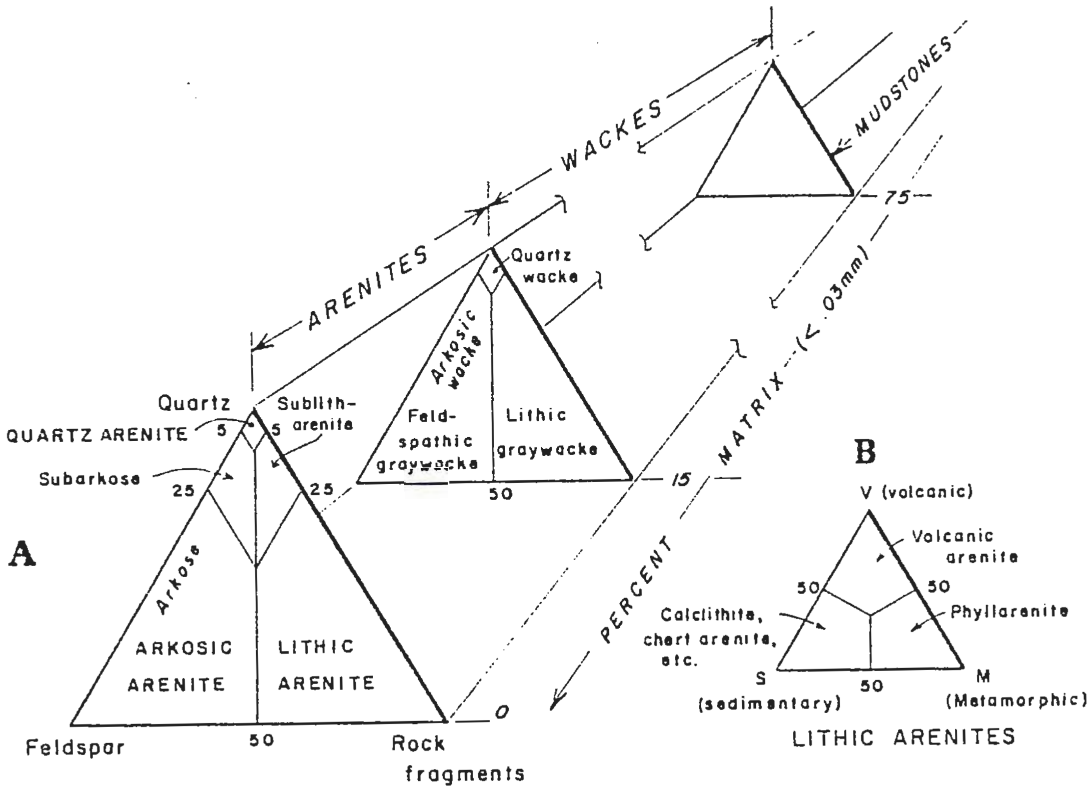

Figure 22: A: classification of terrigenous sandstones (modified from Dott, 1964, Jour. Sed. Petrology, v. 34, Fig. 3);
B: subdivision of lithic arenites (after Folk, 1968, p.124) (from Pettijohn, 1975).

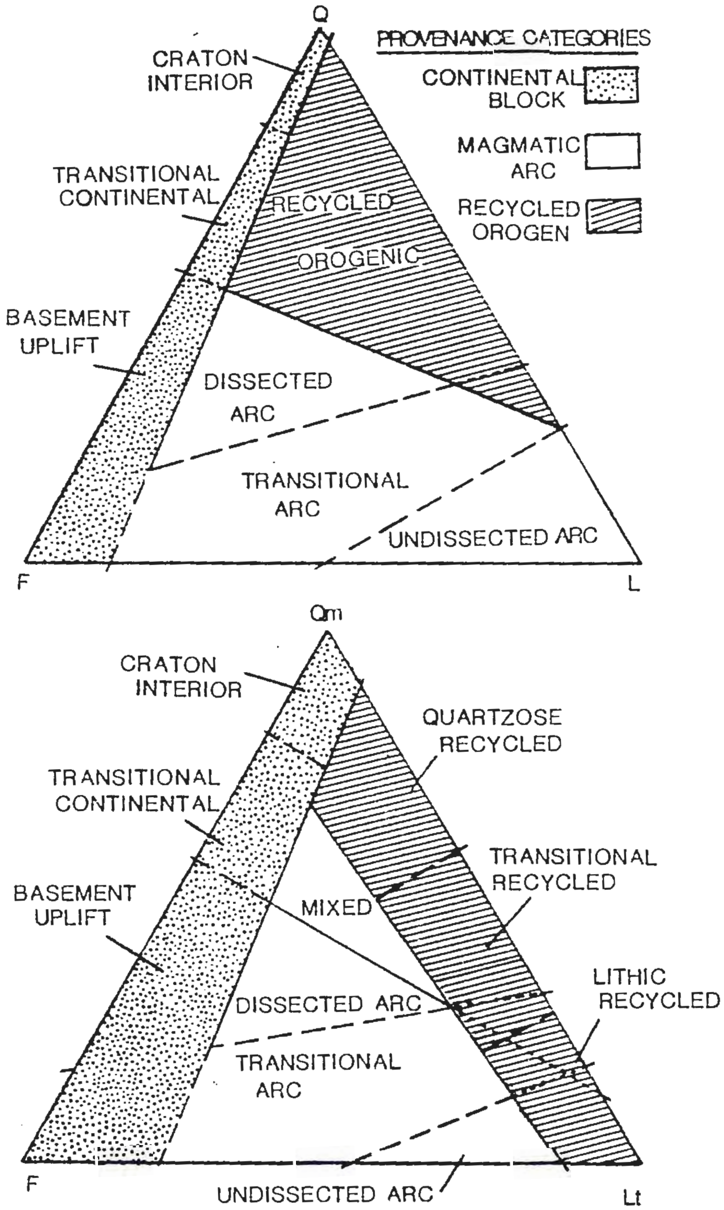

Figure 23: QFL and QmFLt diagrams from Dickinson et al., (1983).

A. For QFL diagrams, the poles are (1) total quartzose grains (Q), including polycrystalline lithic fragments such as chert and quartzite; (2) monocrystalline feldspar grains (F); and (3) unstable polycrystalline lithic fragments (L) of either igneous or sedimentary parentage, including metamorphic varieties.

B. For QmFLt diagrams, the poles are (1) quartz grains (Qm) that are exclusively monocrystalline; (2) feldspar grains (F) as before; and (3) total polycrystalline lithic fragments (Lt), including quartzose varieties.

These ternary diagrams have been subdivided into three types of tectonic source areas: continental blocks, magmatic arcs and recycled orogenic belts (Fig. 23). The three sources are further divided into three sub-provenances based upon different percentages of framework grains. Good detailed descriptions of provenance types are given in Dickinson and Suczek (1979) and Dickinson et al., (1983), and will only be summarized in this text as needed.

Provenance

The twelve sandstone samples from this unit plot in the magmatic arc field on the QFL diagram (Fig. 24). Four samples plot in the undissected arc provenance which is characterized by mainly volcaniclastic material derived from volcanic highlands of either island or continental

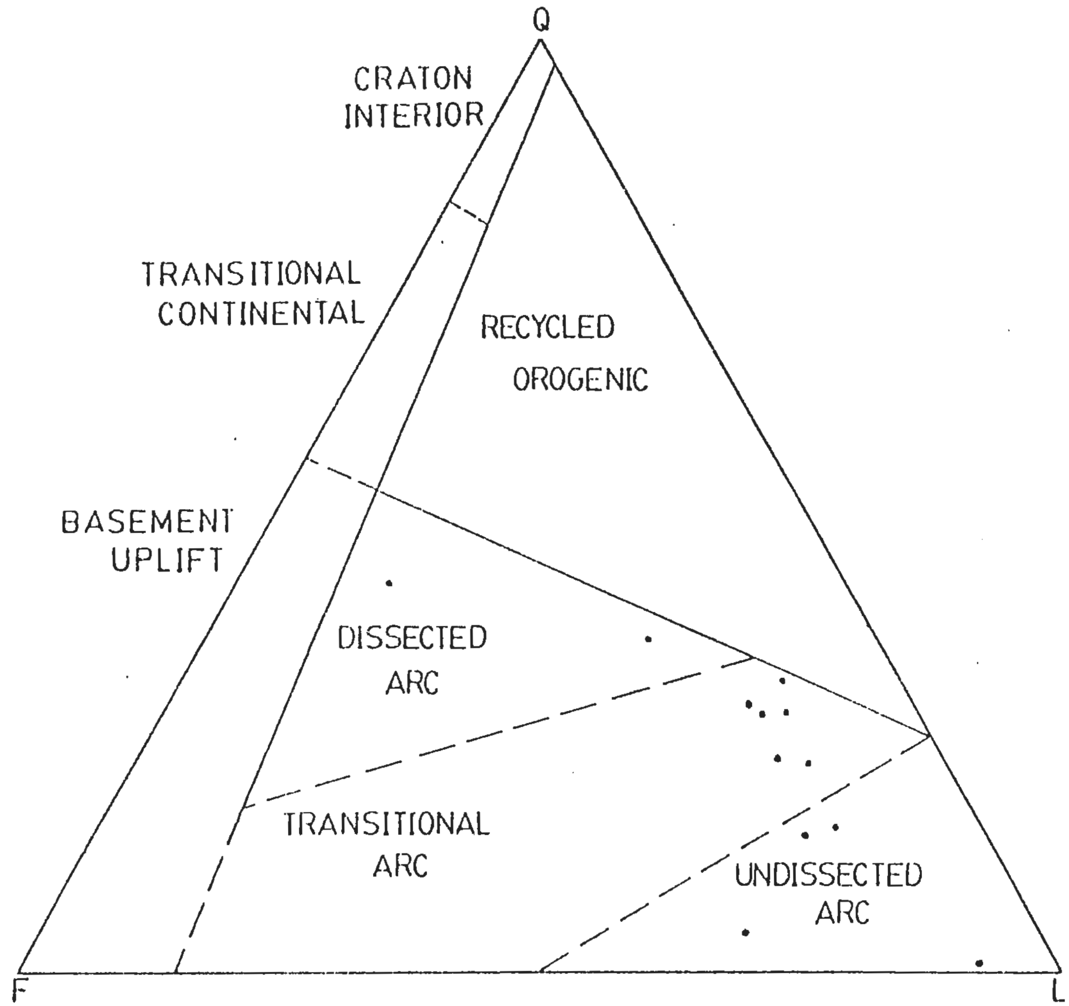

Figure 24: QFL diagram (after Dickinson et al., 1983) for greenish-black sandstones.

margin arcs that have undergone only limited erosion. Six of the samples plot in the transitional arc provenance which indicates deeper erosion of the volcanic highlands with some related plutons being unroofed. The remaining two samples plot in the dissected arc provenance typified by deep erosion of the arc and continued unroofing of plutons commonly combined with continued volcanism.

When plotted on the QmFLt diagram the interpretation is much less clear (Fig. 25). The majority of the samples (7) plot in the magmatic arc field again and the same interpretation can be applied. Three samples have shifted to the transitional recycled provenance, plotting near the dividing line. The transitional recycled field is typical of material derived from foreland fold-thrust belts. Sediments derived from this provenance are mixtures of recycled sedimentary sequences and arc-derived detritus. The positioning of these three samples so near the boundary of the magmatic arc field makes any interpretation questionable. The two remaining samples may represent special cases. One sample plots in the basement uplift provenance of the continental block field; the low lithic component of this sample is probably due to extensive reworking of the more common lithic sandstones. Another sample is also anomalous, plotting in the lithic recycled provenance which is typical of material derived from subduction complexes; the low quartz and feldspar

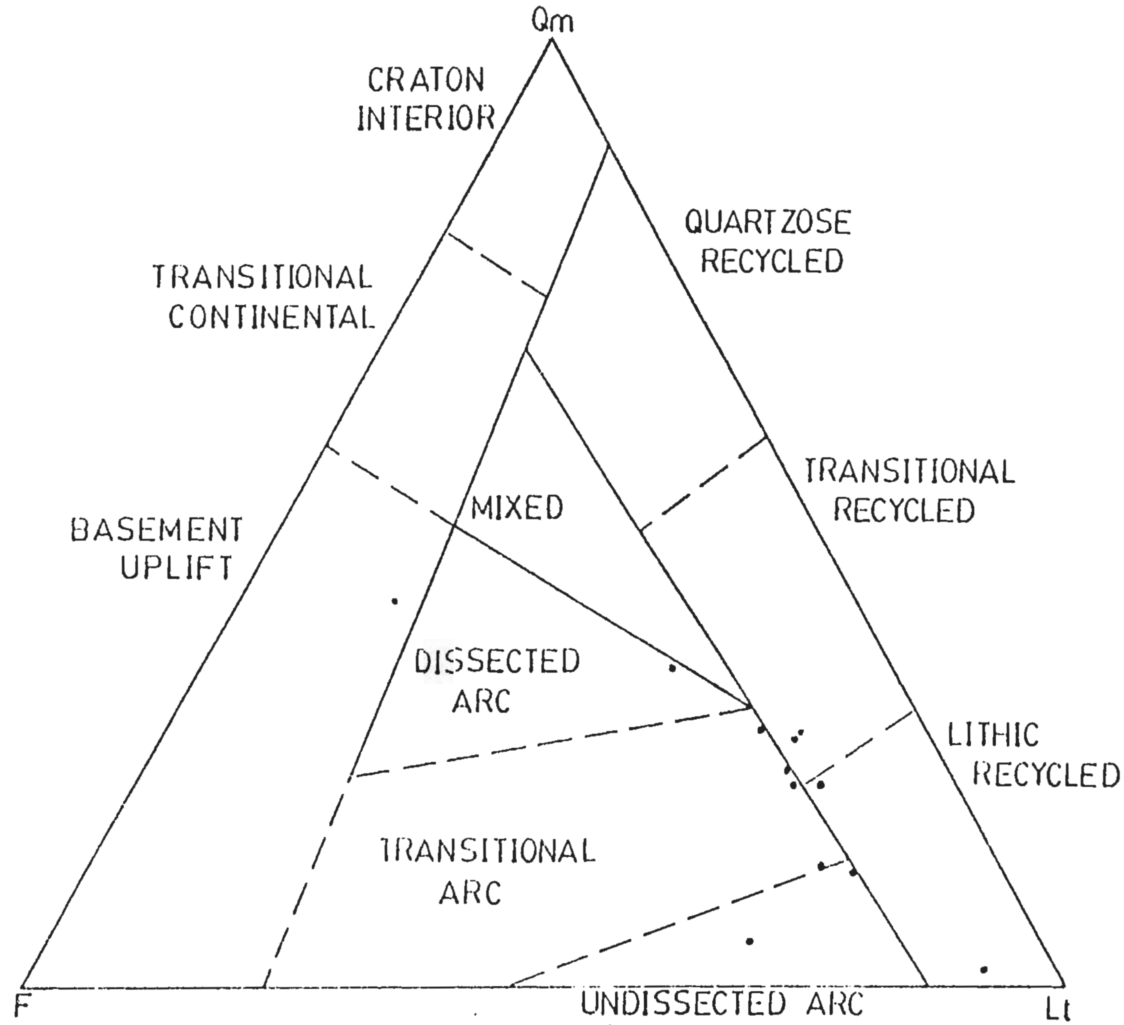

Figure 25: QmFLt diagram (after Dickinson et al., 1983) for greenish-black sandstones.

content of this sample is probably due to the reworking of a pyroclastic unit initially low in these components.

The QFL and QmFLt diagrams indicate that the provenance for these sandstones and conglomerates was mainly a magmatic arc that had been eroded to varying degrees. These sandstones are dominantly epiclastic, composed mainly of grains derived from older lava flows and well indurated pyroclastic flows. The input of a pyroclastic component is often indicated by the presence of very angular clasts that show little evidence of reworking. These clasts include angular fragments of plagioclase phenocrysts attached to devitrified glass fragments. Sediment sources other than the volcanic arc itself are indicated by the presence of both plutonic rock fragments and quartzite clasts. The occurrences of sand-sized plutonic rock fragments and pebbles of tonalitic to granitic composition may be interpreted in several ways; they may have a cratonic source outside the volcanic terrane and were transported into the basin, or they may represent material derived from cogenetic plutons and hypabyssal intrusions unroofed by erosion. The latter interpretation is favored by the author; it is consistent with the transitional arc provenance indicated by the QFL and QmFLt diagrams and the tonalitic compositions are compositionally comparable to the dacitic volcanics common in this sequence.

Pebbles and boulders of pink quartzite had been reported by Weis and LaBerge (1969) within the study area and in units correlated with it, so samples of quartzite were actively sought for this study. Eight cobble-size samples of light pink "quartzite" were collected; of these, six are actually recrystallized felsic volcanics but the remaining two are true quartzites. The modal composition of these samples is shown in Table 2. The presence of quartzite clasts may help in interpreting the type and location of the basin in relation to the arc. The mixing of quartzite clasts with dominantly volcanic sediments may indicate the uplift and erosion of an older sedimentary sequence typical of a stable passive margin. Quartz grains within these clasts have overgrowths of quartz but the well-rounded grains can be seen outlined by fine-grained hematite (Fig.26). These clasts appear to be only slightly metamorphosed, as indicated by little suturing of quartz grains and by the presence of fine-grained sericite between sand grains. This degree of metamorphism is comparable to the sandstones in which these clasts occur.

The source of the quartzite clasts is uncertain; LaBerge and Myers (1984) described similar quartzite clasts up to 25 cm in diameter in conglomerates of similar age to the southeast of the study area. The nearest occurrences of quartzites are xenoliths in the 1500 m.y.

TABLE 2: MODAL ANALYSES OF QUARTZITE PEBBLES (%)

Sample #	QP-1	QP-2
Undulose Unit Quartz	78.8	76.4
Vein Quartz	2.4	0.3
Polycrystalline Quartz	5.5	1.1
Stretched Quartz	2.1	-
Chert	3.3	-
F VRF	-	0.6
Plagioclase (Sericitized)	2.4	13.9
Sericite Matrix	5.2	7.6
Grain Size (Ave.)	1.2mm	1.0mm
Roundness	subang-rnd	subang-rnd
Sorting	mod	mod-well

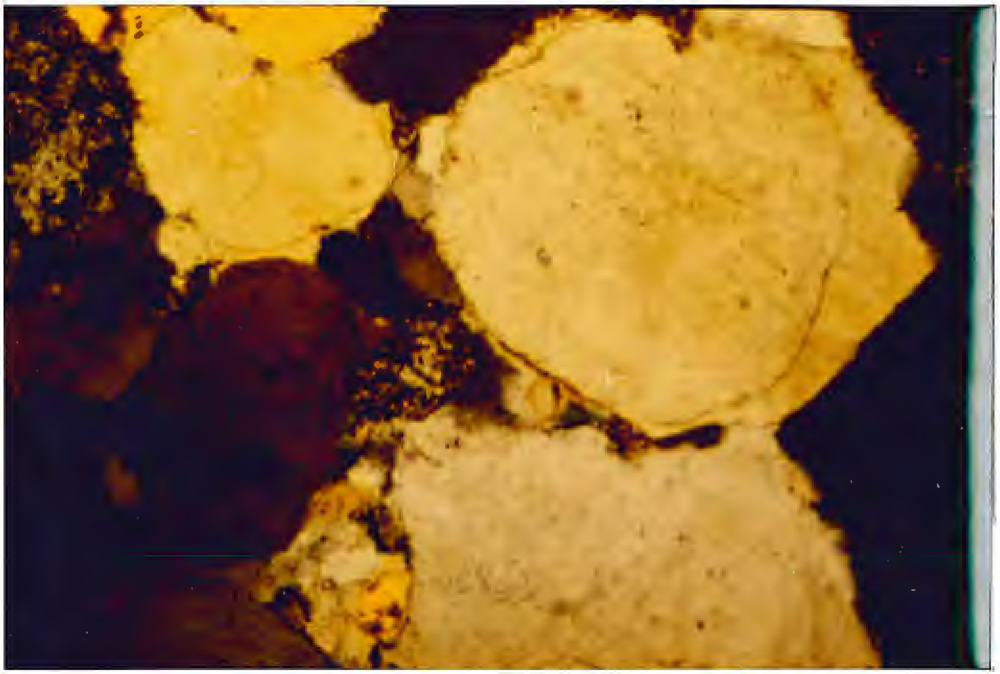

Figure 26: Photomicrograph of quartzite pebble from greenish-black sandstone along U.S. Highway 51. Note well-rounded quartz grains with overgrowths. (Crossed nicols, field of view 4 mm by 3 mm)

Wausau Syenite; the largest of these xenoliths is Rib Mountain in Wausau. The Rib Mountain quartzites are white in color and are metamorphosed to amphibolite facies, characterized by sutured grain boundaries and scattered sillimanite needles. The age of these xenoliths is uncertain; they have been correlated with quartzites of the "Baraboo Interval" (1750-1480 m.y.) which would make them too young to contribute material to an 1850 m.y. old volcaniclastic sequence. The metamorphic history of these xenoliths is also problematic since they represent such high grades compared to the other stratified rocks in the Wausau area. The amphibolite facies metamorphism of these quartzites may be due to either contact metamorphism by the syenites or it may represent an earlier regional metamorphism of a much older sedimentary sequence. Evidence by LaBerge and Myers (1983) suggests that these xenoliths were part of an older regionally metamorphosed sequence and were carried upward by the rising syenite magmas.

The presence of an older sedimentary sequence in the basement would appear to be a possible source for both the quartzite clasts in the volcanic sandstones and the quartzite xenoliths. There are differences between the described quartzites, however; the Rib Mountain quartzite is white while the clasts are red, and the Rib Mountain quartzite is much more metamorphosed. The metamorphic differences suggest that the quartzite clasts, from the volcanic sandstone unit, did not come from a regionally metamorphosed sequence such as LaBerge and Myers (1983) consider the Rib Mountain quartzite to be derived from, but rather from a relatively unmetamorphosed sequence uplifted at the time these volcanic sandstones were being deposited.

Depositional Environment

The interpretation of depositional environment for this unit is based on sedimentary features and textural variations. Sand-sized material ranges from well-rounded to angular, indicating varied transport distances. Cross-bedding is common in some areas; trough type cross-beds are most abundant, though some tabular cross-bedding is also present. The width of the troughs is variable, ranging from small 20 cm wide and 5 cm high troughs to larger ones 2-3 meter wide and 20-30 cm high. These troughs are commonly cut by other troughs. In some exposures the troughs are outlined by abundant magnetite that is probably detrital.

The orientations of trough axes were measured in the field to determine the paleocurrent pattern. A total of 72 measurements were taken; since the dip of the bedding is low ($10-15^{\circ}$) and the measurements are of trough axes, the measurements were not corrected for tilt. When plotted on a rose diagram (Fig. 27) the data indicate a strong unimodal pattern, with dominant transport direction to the W-NW. The calculated variance for these measurements, as described by Potter and Pettijohn (1977), is a low 1704.

A unimodal paleocurrent pattern is associated with several types of depositional environments including alluvial, both braided and meandering streams, eolian, deltaic and marine turbidite (Selley, 1981). The sedimentary features seen in the field do not fit those normally described for either eolian or deltaic deposits. The absence of features such as graded beds and Bouma sequences in this unit makes interpretation as a classical turbidite sequence improbable.

The remaining depositional setting, the alluvial environment, consists of meandering and braided streams. Meandering streams often exhibit a dominant fining-upward sequence represented by coarse channel deposits at the base passing upward into finer grained cross-bedded sands representing point-bar deposits and finally into fine-grained silts and clays representing overbank or flood plain deposits. Meandering alluvial systems generally have highly variable paleocurrent patterns as well (Selley, 1981). Both the fining-upward sequences and the high variance of paleocurrents, which are typical of meandering stream deposits, are absent from this sequence

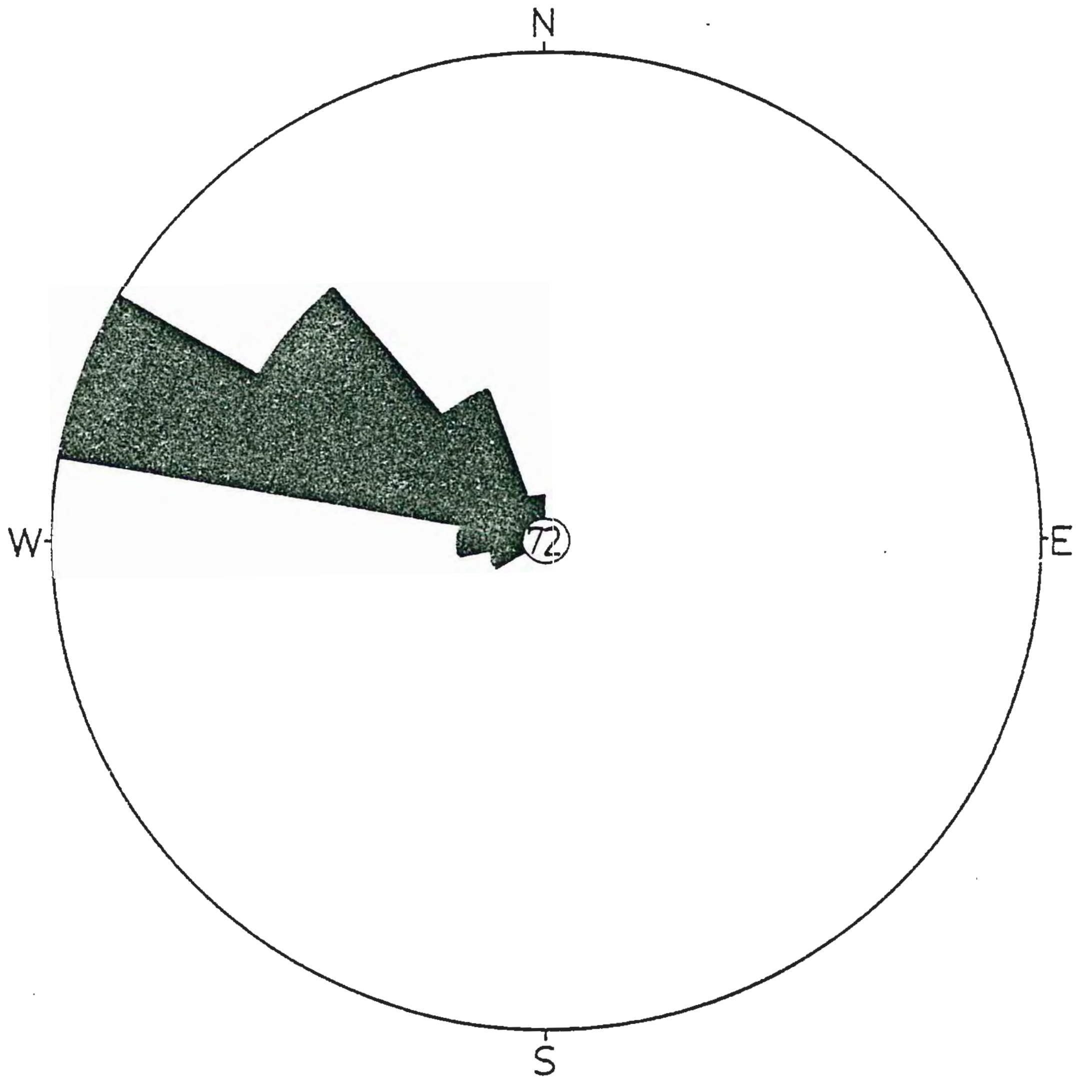

Figure 27: Rose diagram for greenish-black sandstones showing strong unimodal pattern of trough axes (72 measurements). Variance is 1704.

of sandstones, indicating this unit may have been deposited by a braided stream system.

This unit contains many features commonly associated with braided streams, including proximal clast-supported conglomerates of varying thickness, parallel-bedded sandstones, trough cross-bedded sandstones which are abundant in coarse channel deposits in the distal portions of braided streams (Rust, 1981), discontinuous and often channeled beds, and the absence of silt and clays due to high current velocities. Based on the textures of the sandstones and conglomerates, the unimodal paleocurrent pattern, and field relations, this unit is interpreted as a braided stream deposit with sediment sources probably in an easterly directon from the site of deposition.

Red Volcanic Sandstones and Conglomerates

Exposures of this unit are located in the northern portion of the study area, in the SE 1/4, Sec. 35, T. 30 N., R. 7 E.; an exposure along County Highway W in the SE 1/4, Sec. 36, T. 30 N., R. 7 E., is included as part of this unit. The estimated thickness of this unit is 50 m. These sandstones are distinguished by their overall dark red to pink coloration due to small amounts of hematite coating the sand grains. Small, discontinuous beds of pebble conglomerate are interbedded with these sandstones. The thickness of these beds varies from single pebble layers to clast-supported beds up to 10-15 cm thick. Conglomeratic units vary in grain size, but pebbles average 1-2 cm in diameter and are generally well-rounded. The majority of these pebbles are light colored felsic volcanics with lesser amounts of red jasper and mafic volcanics.

Interbedded with these sandstones and conglomerates is a poorly-sorted deposit (including the exposure on County Highway W in the SE 1/4, Sec. 35, T. 30 N., R. 7 E.,) consisting mainly of lapilli-sized angular to subangular volcanic fragments. Thin sections from this unit reveal a complete mixture of at least four clast types, many of which are partially rounded while adjacent clasts are very angular. The majority of the fragments are aphanitic intermediate to mafic volcanics with a low percentage of vesicles. The mafic volcanic fragments may have been derived from the fragmental basalt unit present lower in the section (NE 1/4, SE 1/4, Sec. 36, T. 30 N., R. 8 E.,). These fragments are set in a very fine-grained matrix of sericite and quartz that averages 15-20% of the rock.

The exposures of this poorly-sorted portion are quite poor, so it is difficult to determine if it represents a primary pyroclastic deposit or a debris flow interbedded with the sandstones. The mixing of clast types, the differences in clast shape and the presence of abundant matrix favors the reworking and redeposition of unconsolidated tephra by a debris flow. This poorly-sorted portion is overlain by the well-sorted, fine-grained sandstones and pebble conglomerates that represent the majority of this unit.

Petrography

The grain size of the sandstones ranges from 0.75 mm to 2 mm with an average grain size of approximately 1 mm. Grain shapes range from rounded to subangular. Mineralogically this unit is very immature; the dominant framework grains are felsic volcanic rock fragments with lesser amounts of intermediate composition grains also present. Quartz as unit grains and as polycrystalline and chert grains are second in abundance. Mafic volcanic rock fragments and plutonic rock fragments are minor components. Plagioclase feldspar grains are not abundant in these sandstones and conglomerates. The low feldspar content of the rock fragments indicates this is due to a lack of plagioclase in the source rock rather than due to some secondary cause.

Provenance

The modes of four sandstone samples were determined by point counting; the results of these point counts are listed in Table 3. These samples are lithic arenites according to Dott's (1964) classification of sandstones, and more specifically volcanic arenites after Folk (1968). These samples were also classified using the Dickinson et al. (1983) classification, in an attempt to interpret the tectonic environment. These samples were plotted on both the QFL and the QmFLt diagrams. On the QFL diagram all four samples plot toward the edge of the diagram near the right corner (Fig. 28) due to their low feldspar content. Two samples plot in the field of recycled arc orogen, a provenance characterized by uplifted and eroded subduction complexes, collision complexes and foreland fold-thrust belts. The remaining two samples fall in the undissected arc field. This field represents material derived from active volcanic highlands that have undergone little erosion; sources may be either island arcs or continental margin arcs.

When these samples are plotted on the QmFLt diagram (Fig. 29) three samples cluster in the lower right corner in the lithic recycled field. Dickinson and Suczek (1979) found that sediments derived from uplifted subduction complexes dominate this field. The remaining sample plots in the transitional recycled field, perhaps because

TABLE 3: MODAL ANALYSES OF RED VOLCANIC SANDSTONES (%)

Sample #	W84-38	W84-40	W84-43	W84-44
Undulose Quartz	19.3	6.8	8.8	8.3
Polycrystalline Quartz	7.9	6.3	15.7	1.6
Plagioclase	3.3	0.6	0.9	-
F VRF	37.2	54.8	48.6	57.3
F-IVRF	11.8	11.5	0.5	1.6
M VRF	0.8	-	-	0.6
Plutonic RF	0.9	1.8	-	0.3
Magnetite	6.5	1.8	1.3	0.6
Epidote	-	-	-	-
Chlorite	-	-	3.3	13.5
Sericite Matrix	12.1	14.1	20.9	5.8
Chert Cement	-	-	-	10.0
Grain Size (Ave.)	0.75mm	1.5mm	1mm	1mm
Roundness	rnd-subang	rnd-subang	rnd-subang	rnd-subang
Sorting	well	mod	poor	mod

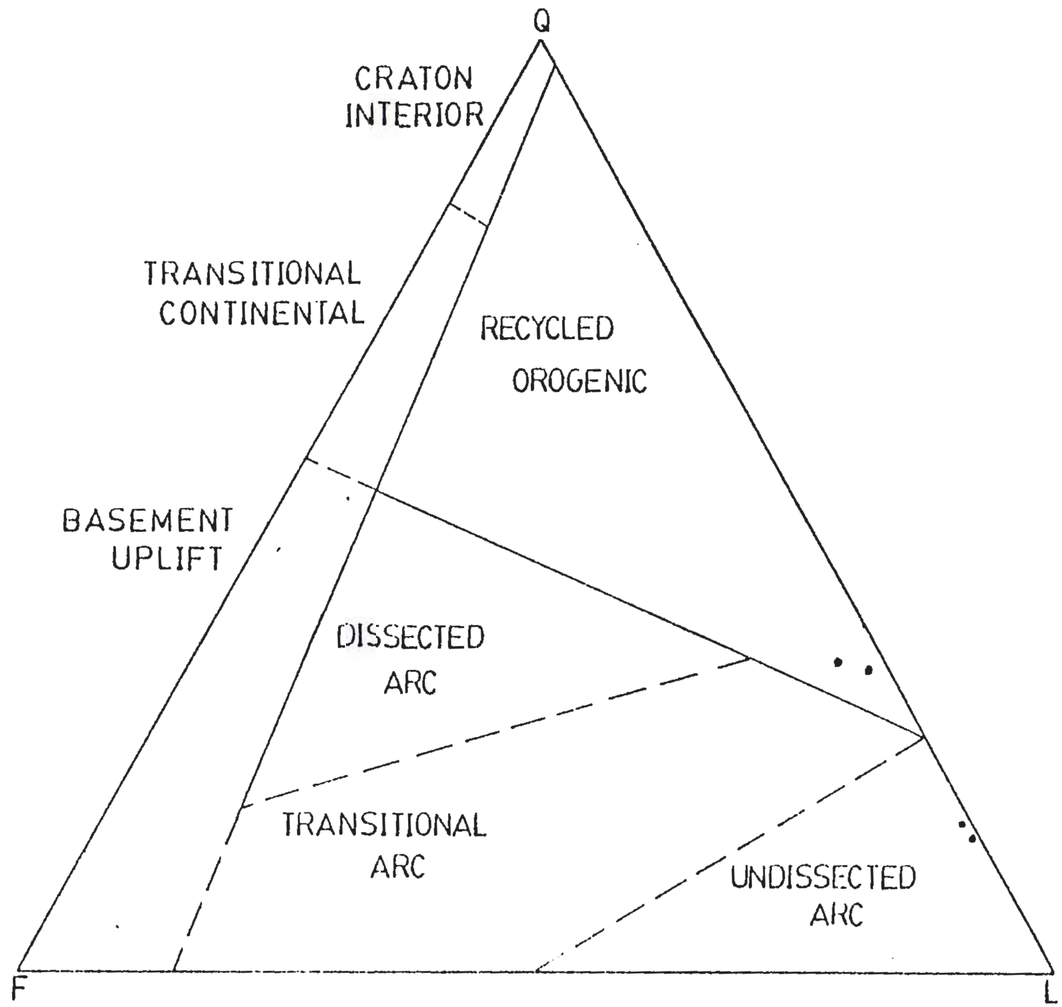

Figure 28: QFL diagram (after Dickinson et al., 1983) for red sandstones.

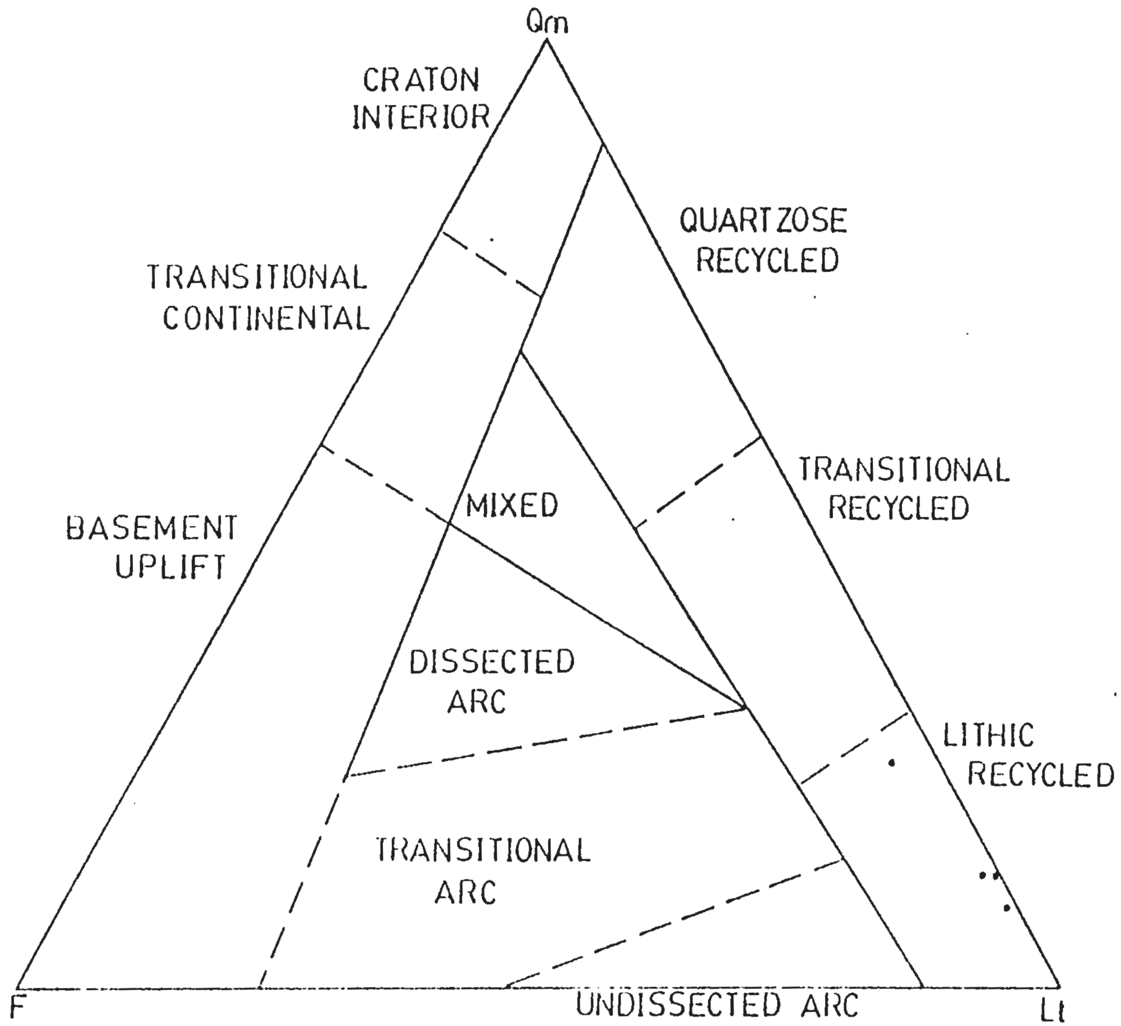

Figure 29: QmFLt diagram (after Dickinson et al., 1983) for red sandstones.

it is much finer-grained and many of the large volcanic fragments have been sorted out.

Four samples are insufficient to accurately characterize a tectonic environment, but the nature of the provenance is suggested by the lithic fragments. The abundance of felsic to intermediate volcanic fragments and the low percentage of mafic clasts may indicate derivation from a continental margin volcanic field where felsic volcanics are common. The low percentage of plutonic rock fragments derived from hypabyssal intrusions suggests that little erosion of the volcanic field had occurred at the time these sediments were deposited.

Depositional Environment

The depositional environment of this unit is unknown due to insufficient and poor exposure. Trough cross-bedding and interbedded sandstones and conglomerates suggest a fluvial environment similar to that described for the previous sandstone unit. Cross-bedding, though present, is generally unusable as it is found on blocks which are no longer in place, so a paleocurrent pattern is not available to support a specific environment. These sandstones and the associated fragmental unit have a distinctive red coloration which is common in rocks deposited in an oxidizing environment (Collinson, 1978). Walker (1967) indicated that the development of a red coloration is more diagnostic of the diagenetic environment than the climatic conditions, with the red coloration forming due to the breakdown and oxidation of iron-rich minerals such as hornblende and biotite. Conditions favorable for oxidation to occur are common today in a subaerial environment with a low water table, but it does not form exclusively under these conditions. The presence of fluvial sandstones higher in the section (Fig. 30) and the similar features of these sandstones and conglomerates may suggest a fluvial origin for this unit as well.

Bedded Siltstones and Tuffs

This unit is located on the east side of the Wisconsin River near the center of the study area. This unit has a minimum thickness of 250 meters, strikes nearly north-south through most of the area, and dips to the west at 10 to 30 degrees. It overlies the red sandstone and conglomerate unit described above (Fig. 30). The best exposures are located along County Highway W and along the railroad tracks on the east side of the river. These rocks are greenish black on a fresh surface and gray to rusty brown on a weathered surface. They range from very fine-grained to medium-grained, averaging 0.25 mm in grain

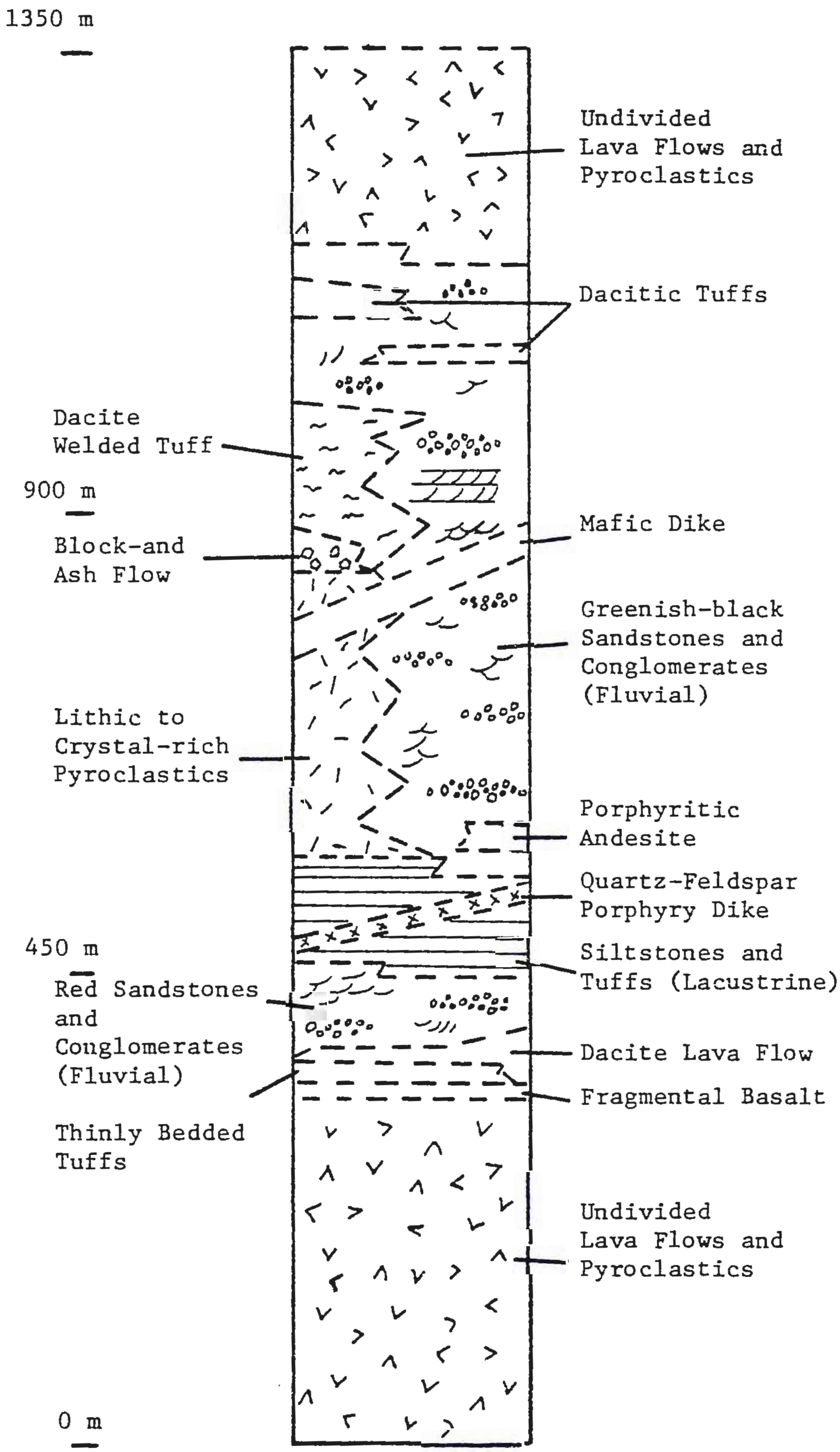

Figure 30: Idealized Stratigraphy of the study area and interpretation.

size. The fine grain size made point-counts impractical, but the siltstones are composed mainly of angular quartz, altered plagioclase, sericitized volcanic rock fragments and chlorite with minor epidote and pyrite; some beds also contain well-preserved relict shards. This fine-grained unit represents the argillite described by Emmons and Snyder (1944) in their study of the Wausau area. They described three rock types in this unit as massive, banded and sericitized argillite. These sedimentary rocks are well-bedded with some massive beds up to 1 meter thick; the majority are much more thinly bedded and finely laminated. The very thinly-bedded portions have the appearance of varved sediments due to their alternating light and dark colored bands. The light colored bands tend to be somewhat coarser-grained and contain less chlorite than the dark layers. The light colored layers frequently show normal graded bedding, which is seen with some difficulty in the field, but is easily seen in thin section (Fig. 31). These graded units are generally less than 4 cm thick.

Bedding in this unit ranges from evenly bedded to slightly wavy bedded and some thin layers appear to lens in and out. Contorted bedding is present at the south end of the exposure on Highway W and appears to be due to soft-sediment deformation rather than tectonic folding. These deformed units vary in thickness from 5 cm to 3

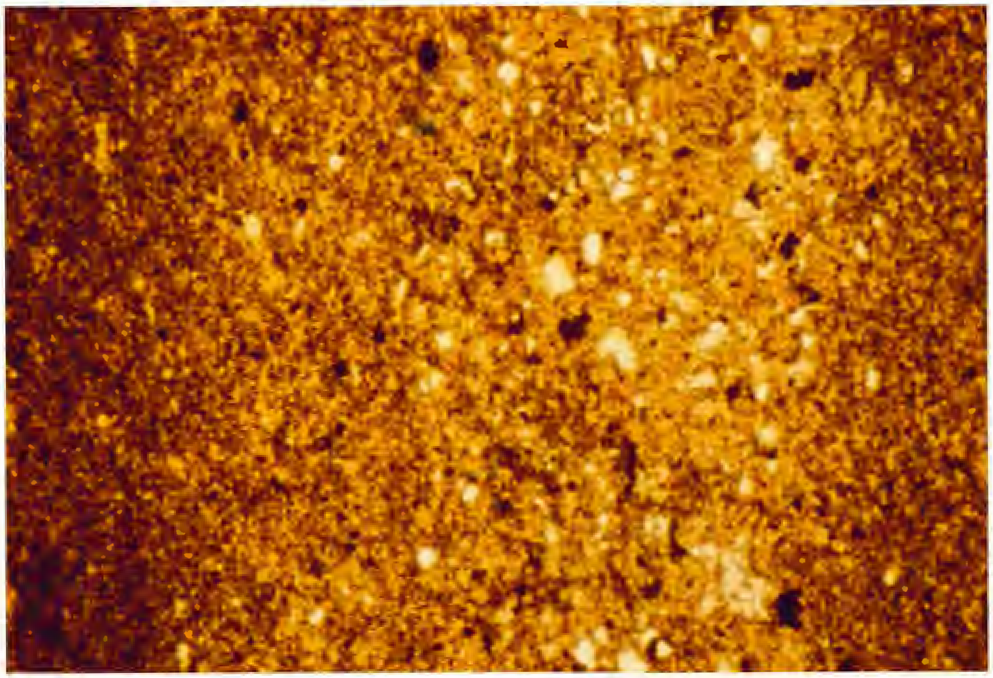

Figure 31: Graded bed from siltstone unit along County Highway W. (One polar, field of view 1.5 mm by 1 mm)

Figure 32: Synsedimentary folds in siltstone along County Highway W.

meters, and often involve several beds (Fig. 32). On several exposures these contorted beds are sandwiched between undisturbed beds, indicating that the deformation took place prior to deposition of the overlying bed. Several of these deformed beds contain folds that appear to have been truncated by the overlying bedding plane (Fig. 33), also indicating the bed was folded and eroded slightly before the next bed was deposited. The axes of the soft sedimentary folds strike to the W-NW and many are overturned to the north. Slump folds such as these have been used in other studies to give an indication of paleoslope. These studies assume that fold axes strike perpendicular to the down-slope direction. This assumption may be invalid, however; Lajoie (1972) mapped a small slump on a well exposed slope and found that fold axis orientation varies considerably and may actually parallel the slope direction, with folds overturned both downslope and upslope. Soft-sediment folding is often closely associated with dewatering features such as "dewatering volcanoes" (Fig. 34), which form due to compaction of the sediments and the expulsion of water. Some beds were probably also deformed after the deposition of overlying beds; this is indicated by the presence of sandstone dikes which cut not only the siltstone but have also been observed cutting overlying tuffs. Sandstone dikes may form when water-saturated sediments become

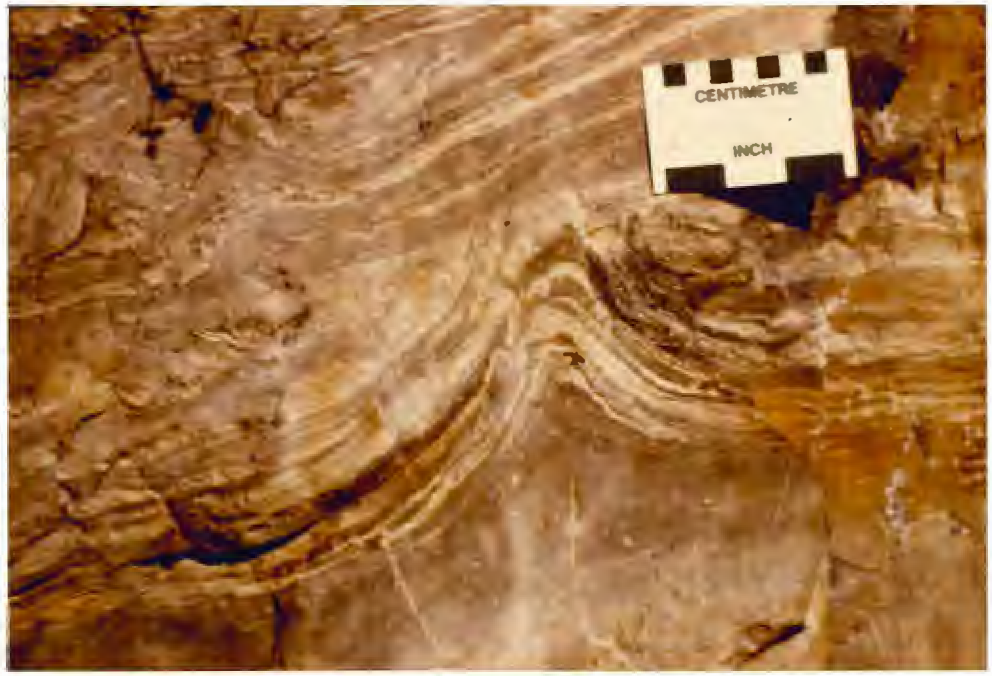

Figure 33: Truncated crest of synsedimentary fold, indicating slight erosion. From siltstone along County Hwy. W.

Figure 34: "Dewatering volcanoes" in siltstone along County Hwy. W.

"quick" and the hydrostatic pressure created by the overlying beds allows injection of the material along fractures (Pettijohn, 1975, p.148). There are also many examples of load structures of various sizes (Fig. 35) in which the overlying bed has deformed the underlying beds.

Exposures located along the northern margin of the study area have been correlated with this unit by the author. These rocks contain angular quartz, plagioclase, felsic to intermediate volcanic rock fragments and varying amounts of chlorite, sericite, magnetite, epidote and pyrite, and are slightly coarser-grained than those described previously. Some of these beds are cross-bedded, indicating that some reworking has occurred. This may also suggest that water was shallower than further south. The increased grain size and cross-bedding may indicate a facies change to a more near-shore environment.

The unit as a whole is very fine-grained but several coarse units less than 10 cm thick are present. These beds are composed of volcanically derived clasts ranging from ash to lapilli sized. These fragments are angular to subangular with a maximum diameter of 1 cm; many are porphyritic, and relict glassy textures such as perlitic cracks that formed due to hydration of the glass are present (Fig. 36). The angular fragments are also associated with well-preserved shards. These coarse units also contain abundant broken feldspar crystals.

Figure 35: Load structure in a siltstone bed along County Hwy. W.

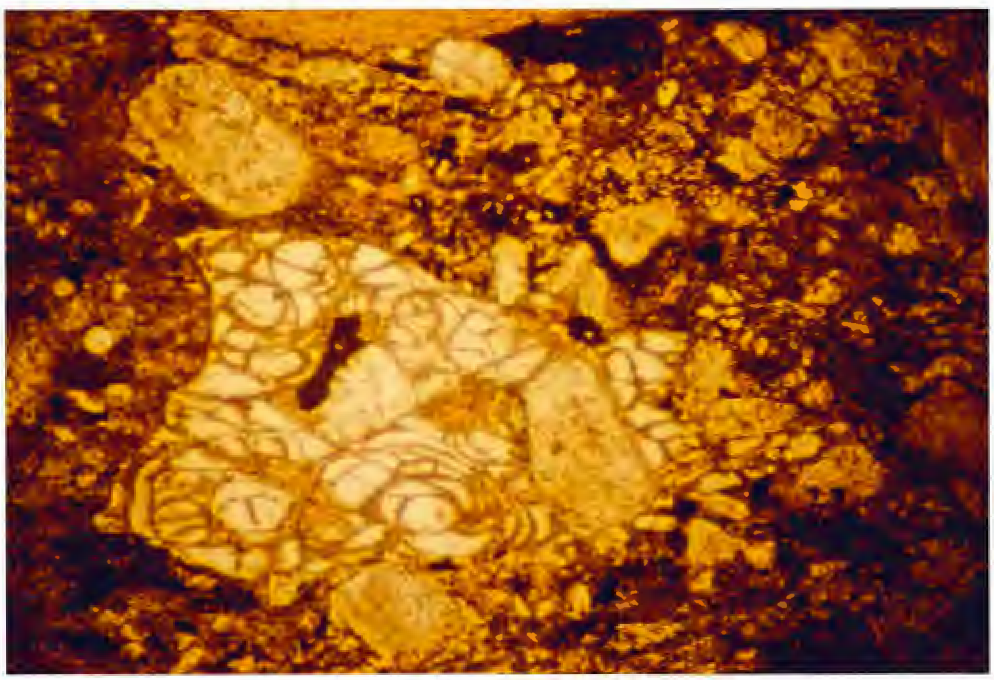

Figure 36: Devitrified glassy fragment with perlitic cracks in tuffaceous siltstone along County Hwy. W. (One polar, field of view 4 mm by 3 mm)

Provenance

There appears to have been very little reworking of material following deposition. Sand-sized grains are quite angular and delicate glass shards have been preserved, showing no sign of rounding (Fig. 37). The presence of evenly laminated beds and graded beds also indicates little movement of material. Wolf and Ellison (1971) describe similar evenly bedded and laminated tuffs and siltstone in Pliocene lake beds in Oregon; these thinly bedded sediments were partially interpreted as airfall pyroclastics, but also suggested that some of them represented deposition of material by slow moving currents. In the study area, some of the graded and laminated beds, especially those containing relict shards, probably include some ash and lapilli-sized material deposited as airfall. Airfall material can become graded as it settles through an air or water column. The majority of the graded beds probably represent material deposited on land and then washed (i.e., redeposited) into the basin. The rapid input of material into the basin may have formed small turbidity flows that resulted in graded beds. Turbidity currents are most common in deep marine settings, but they are also found in lakes due to slumping and input of material by sediment-laden rivers (Collinson, 1978).

This unit coarsens upward and grades into a

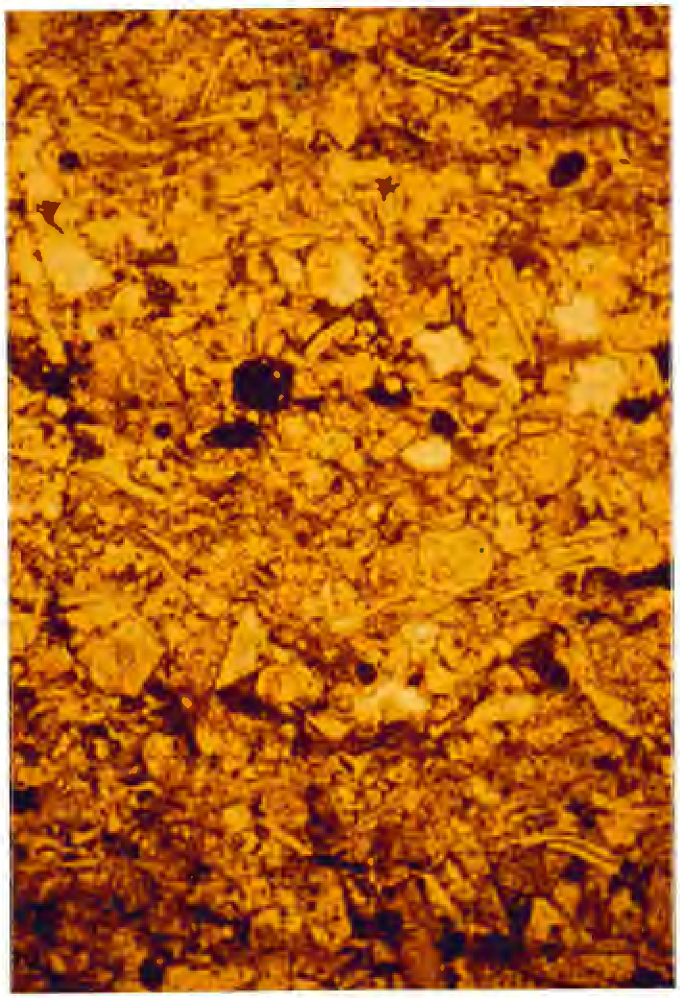

Figure 37: Well-preserved devitrified glassy shards in tuffaceous siltstone unit. (One polar, field of view 2.5 mm by 1.5 mm)

fine-grained variety of the greenish-black sandstone unit described previously. These sandstones are extensively reworked, and contain well rounded pebbles and abundant trough cross-bedding. Trough axes orientations indicate a strong unimodal transport direction to the W-NW. The unimodal paleocurrent pattern combined with the coarsening-upward trend indicates a shift to the fluvial environment that deposited the dark sandstones and conglomerates on the east side of the Wisconsin River.

Depositional Environment

The interpretation of a depositional environment for this unit is based on its physical characteristics such as grain size, bedding, and lamination and its occurrence with other units in the section. The presence of laterally continuous, thinly bedded and laminated beds which show little or no reworking indicates deposition of material in a restricted environment and below wave base. There are two environments that typically provide such a setting, deep marine and lacustrine. Unfortunately, one of the main criteria for distinguishing between these environments is paleontology, which cannot be used for this unit. These two environments produce many of the same features including finely laminated to massive bedding, synsedimentary slumped and folded beds, and graded beds. These shared features make a definite determination of depositional setting impossible; however there are some features that are particularly suggestive of a lacustrine environment. Lakes typically have shallow wave bases due to their small size; this results in limited agitation allowing the deposition and preservation of finely laminated bedding. Such lamination is common in lacustrine sediments but is not diagnostic (Picard and High, 1972). Lacustrine deposits are closely associated with fluvial environments (Cant, 1982) and the occurrence of "fluvial deposits surrounding a suspected lacustrine sequence is suggestive of a lacustrine origin" (Picard and High, 1972). Lacustrine deposits also typically show a regressive trend, becoming coarser grained upward, as the basin fills (Selley, 1981). The bedded siltstone and tuff unit grades upward into fine-grained cross-bedded sandstones which are interpreted as fluvial. It is also apparently underlain by the red colored sandstones with fluvial affinities described previously. The absence of pillowed basalt units in the entire volcanic sequence may indicate a subaerial environment rather than a marine setting. The physical character of this unit and the close association with fluvial sandstones suggests deposition in a lacustrine environment.

V. STRUCTURE AND METAMORPHISM

STRUCTURE

The sequence of rocks in the study area is relatively undeformed. Structural data collected during this study were found mainly in sedimentary rocks. The most abundant structural indicators are bedding, cross-bedding and graded beds which indicate a westward topping direction throughout the study area. Bedding consistently strikes NW to NE and dips westerly at 10 to 30 degrees. Structural features such as cleavage and foliation are poorly developed or absent throughout the study area; too few of these features were measured to plot on a stereonet but the orientations of cleavage and foliation are shown on the geologic map (Plate 1).

Folds

Small scale folds, other than synsedimentary folds, are absent from any of the units allowing no direct interpretation of major fold orientations. In order to interpret the major structure, bedding orientations were plotted on a stereonet as poles to bedding (Fig.38). Sixty-one measurements were plotted by hand and contoured; the pattern seen from this plot shows a concentration to

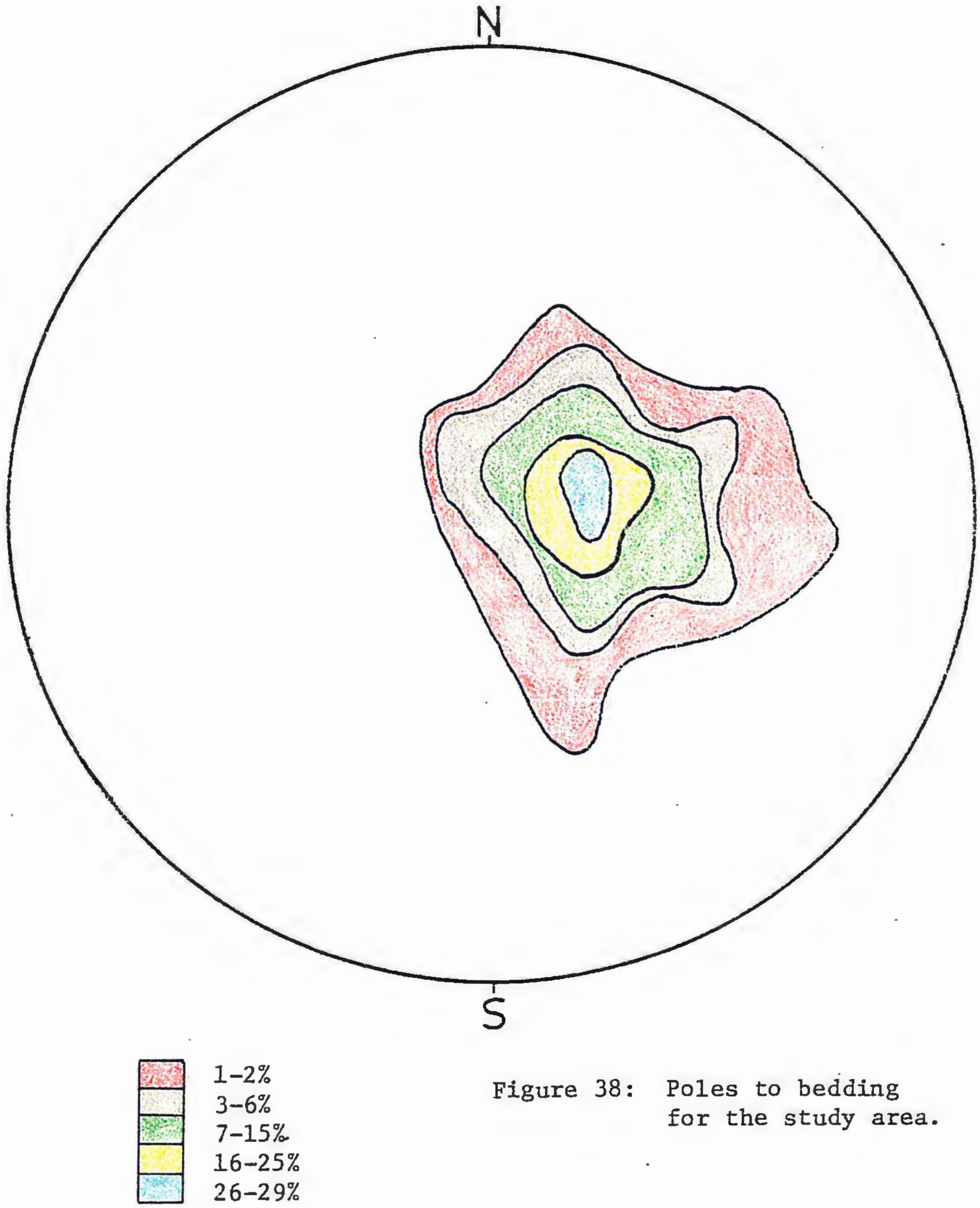

Figure 38: Poles to bedding for the study area.

the right of center indicating a gentle dip to the west but does not define a fold. LaBerge, Schulz and Myers (1984) described gentle folds in a sequence correlated with this one, southeast of the study area, plunging to the west at 10 to 20 degrees.

Faults

The most common deformational features in the study area are faults. LaBerge and Myers (1983) placed faults at the north and southeast boundaries of the area of this investigation and indicated a possible fault on the south side as well. These faults are not exposed but their presence seems likely, based on topographic features and lithology changes. The northern boundary fault may be related to a group of smaller faults that cut exposures along U.S. Highway 51. Two faults associated with this zone occur in the volcanic sandstone along the highway (SW 1/4, Sec. 34, T. 30 N., R. 7 E.); material in the fault planes is highly oxidized and appears somewhat foliated. Movement along these faults could not be determined due to the homogeneity of the sandstone on both sides of the zone. Major movement along these zones should have resulted in the juxtaposition of differing rock units. The next exposure north along the highway is a different rock unit, the thinly bedded to massive tuff unit, and is separated from the sandstones by a topographic low, which may be due to erosion along a fault zone. This tuff exposure is cut by many small scale faults (Fig. 12) and may be part of a tilted block from lower in the section. The contact between this tuff unit and the quartz monzonite body, exposed to the north, is not exposed but may also be a fault contact.

Other small scale-faults and shear zones are present throughout the study area. A small intensely deformed zone on the NW side of the southbound ramp onto Highway 51 trends northeasterly and is less than 30 cm wide where it is exposed. Rock samples from this zone are foliated and most recognizable clasts are elongate lens-like shapes indicating some shearing. High-angle reverse faults striking to the northeast are common in the sandstone unit; most of these faults have offsets of 5 cm or less but some have offsets of up to a meter. Occasionally a thin fault breccia with a chloritic matrix is seen, as at the fault cutting the tuffaceous siltstone in the SW 1/4, Sec. 2, T. 29 N., R. 7 E.

METAMORPHISM

The rocks in the study area have been grouped with dominantly greenschist facies volcanic rocks on the Bedrock Geologic Map of Wisconsin (Mudrey et al., 1982), but they have been described as "virtually unmetamorphosed" and separated from the greenschist facies sequence by LaBerge, Schulz and Myers (1984). LaBerge and Myers (1983) describe a "chilled zone and a contact metamorphic halo" in the volcanic rocks along the southern margin of the Granite Heights granite pluton, including the rocks of the study area.

The fine grain size and the preservation of delicate volcanic textures indicate an overall lack of recrystallization (LaBerge and Myers, 1983) such as is commonly associated with metamorphism. The low metamorphic grade of these rocks is indicated by their lack of a distinct foliation and by the assemblage of minerals: chlorite, sericite, epidote, actinolite, albite, $\pm$ calcite. This metamorphic assemblage is typical of both the greenschist facies of regional metamorphism and the albite-epidote hornfels facies of contact metamorphism (Turner, 1981). These facies are mineralogically indistinguishable in mafic rocks (Kuniyoshi and Liou, 1976), and other relationships must be used to differentiate them.

The metamorphic assemblage is unevenly distributed throughout the area and appears to be more prevalent on the northern side. This may be partially due to lack of suitable rock types, but may also indicate a contact metamorphic effect due to the emplacement of the Granite Heights pluton present to the north of the study area.

The chilled zone and metamorphic halo described by LaBerge and Myers (1983) were not recognized by the author in the field, but one feature was seen that may suggest contact metamorphism. The exposure on the west side of the bridge across the Wisconsin River from Brokaw is a dark green volcanic sandstone cut by a mafic dike. This dike contains occasional round clusters of epidote up to 3 cm in diameter; Kuniyoshi and Liou (1976) have described similar epidote "spherules" in mafic volcanic rocks in the contact aureole of Coast Range intrusions in British Columbia and these may have a similar origin.

Contact metamorphism probably is not solely responsible for the metamorphic features seen in these rocks and a regional low grade metamorphic event is likely. The preservation of undeformed shard structures and only minor foliation indicates a low-pressure regional metamorphism. The preservation of original textures in rocks of simple structure and lacking a penetrative deformation is common in rocks that have undergone burial metamorphism (Turner, 1981). Burial metamorphism as defined by Turner (1981) is a type of regional metamorphism with mineralogy controlled by depth of burial in volcanic and sedimentary piles. The preservation of relict textures can occur because mineral growth occurs in the solid state and on a very small scale resulting in fine-grained replacement minerals (Best, 1982).

Metamorphism of this type merges with deep diagenesis at the low temperature end and grades into greenschist facies regional metamorphism as the temperature increases. Burial metamorphism of volcaniclastic rocks containing unstable glasses is common and may show the facies series: zeolite to prehnite-pumpellyite to pumpellyite-actinolite to greenschist, and mineralogic changes may be incomplete resulting in the association of original minerals and metamorphic minerals (Turner, 1981).

The lack of burial metamorphic assemblages in the volcaniclastic rocks in the study area suggests that conditions were not favorable for their preservation. The development of burial metamorphic facies is temperature dependent and with increasing temperatures the zeolite facies is destroyed. The destruction of the zeolite facies minerals marks the normal transition to the prehnite-pumpellyite facies. In many cases the zeolite facies passes directly into the greenschist facies without the appearance of prehnite-pumpellyite (Best, 1982). The direct transition from zeolite to lower greenschist facies is dependant not only on the temperature but also on the concentration of CO_2 and H_2O. The breakdown of zeolite minerals under low H_2O concentrations and higher CO_2 concentrations suppresses the formation of prehnite, pumpellyite and epidote (Best, 1982).

A low grade regional metamorphic event has been documented at approximately 1,615 - 1,630 m.y. ago by Van Schmus (1980). Van Schmus postulates that this event was responsible for the deformation and low grade metamorphism seen in many of the quartzites in parts of Wisconsin that are younger than the volcanics in the study area. This metamorphic event may also be responsible for the metamorphism of the mafic dikes seen in the 3M quarry and along U.S. Highway 51.

All three types of metamorphism contact, regional and burial, may have occurred. Thick sequences of volcanic sandstones containing unstable volcanic glass are likely to be altered by diagenesis or burial metamorphism to more stable components. In this case the silicic glass has gone mainly to fine-grained quartz which is stable under most metamorphic conditions. The subsequent emplacement of a granitic pluton and the low grade regional metamorphism which may have occurred in this area would have little effect on the felsic rocks but may be responsible for some textures in the mafic rocks. The effects of a low grade regional metamorphic and deformational event may be responsible for the development of localized foliations and the tilting of the volcanic-sedimentary sequence.

VI. GEOCHEMISTRY

Six chemical analyses of rocks from the study area were available for this study, four unpublished analyses from the U.S.G.S and two analyses from LaBerge and Myers (1983). These analyses are shown in Table 4. The SiO_2 content of these samples varies from 54 to 68%, placing them in the range of andesites to dacites. Micheal Carr's IGPET computer program was helpful in plotting these analyses.

The interpretation of these chemical data must remain limited due to the small number of samples and the lack of a basalt analysis; however, the basic character of the rocks can be determined. The analyses were plotted on an Alkali vs. SiO_2 variation diagram (Fig. 39) to differentiate alkaline suites from subalkaline suites. The samples plot in the subalkaline field, to the right of the dividing line proposed by Irvine and Baragar (1971). These authors also subdivided the subalkaline volcanic rocks into basalt, andesite, dacite or rhyolite based on the color index (CI) vs. the normative plagioclase composition (An). This classification places the six samples in the andesite, dacite and rhyolite fields (Fig. 40).

Subalkaline rocks may be further divided into

TABLE 4: CHEMICAL ANALYSES (*)

	RRT-1	3M-68	MSW-10A	MSW-10B	MSW-10C	MSW-11A
SiO_2	54.3	68.2	65.6	64.1	61.2	69.4
TiO_2	0.88	0.49	0.71	0.85	0.77	0.32
Al_2O_3	17.7	14.8	15.1	17.1	15.4	16.3
Fe_2O_3	1.27	2.17	4.7	5.1	5.3	2.0
FeO	5.29	2.74	1.6	0.72	0.76	0.92
MnO	0.12	0.05	0.05	0.05	0.09	0.03
MgO	2.03	0.57	1.5	0.83	1.4	1.7
CaO	5.70	1.62	2.6	1.4	3.4	0.33
Na_2O	4.74	4.06	4.0	5.9	5.1	2.6
K_2O	1.80	3.64	2.0	1.7	1.8	3.4
P_2O_5	0.43	0.06	0.37	0.42	0.38	0.09
H_2O^+	2.20	0.87	1.4	0.93	1.2	2.3
H_2O^-	0.11	0.07	0.21	0.20	0.19	0.50
CO_2	3.89	1.12	0.08	0.02	1.6	0.02
TOTAL	100.46	100.46	99.92	99.32	98.59	99.91
Trace elements (ppm)						
Nb		30	20	23	17	9
Rb		77	50	43	34	84
Sr	680	255	440	367	395	158
Zr		350	215	252	219	151
Ba		1560				1030

(*) See Appendix 1 for sample locations.

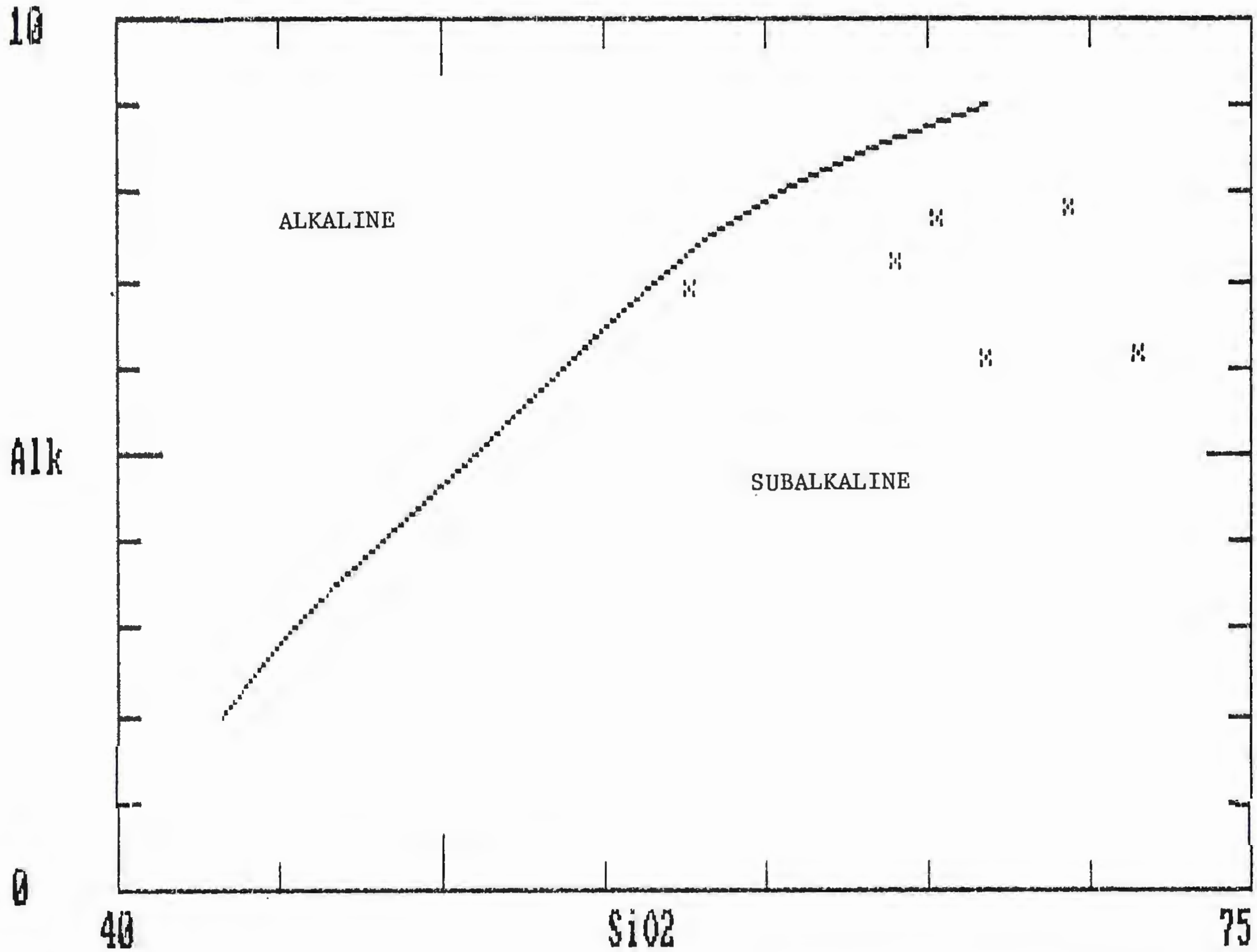

Figure 39: Alkalies versus silica diagram, dividing line between alkaline and subalkaline fields after Irvine and Baragar (1971).

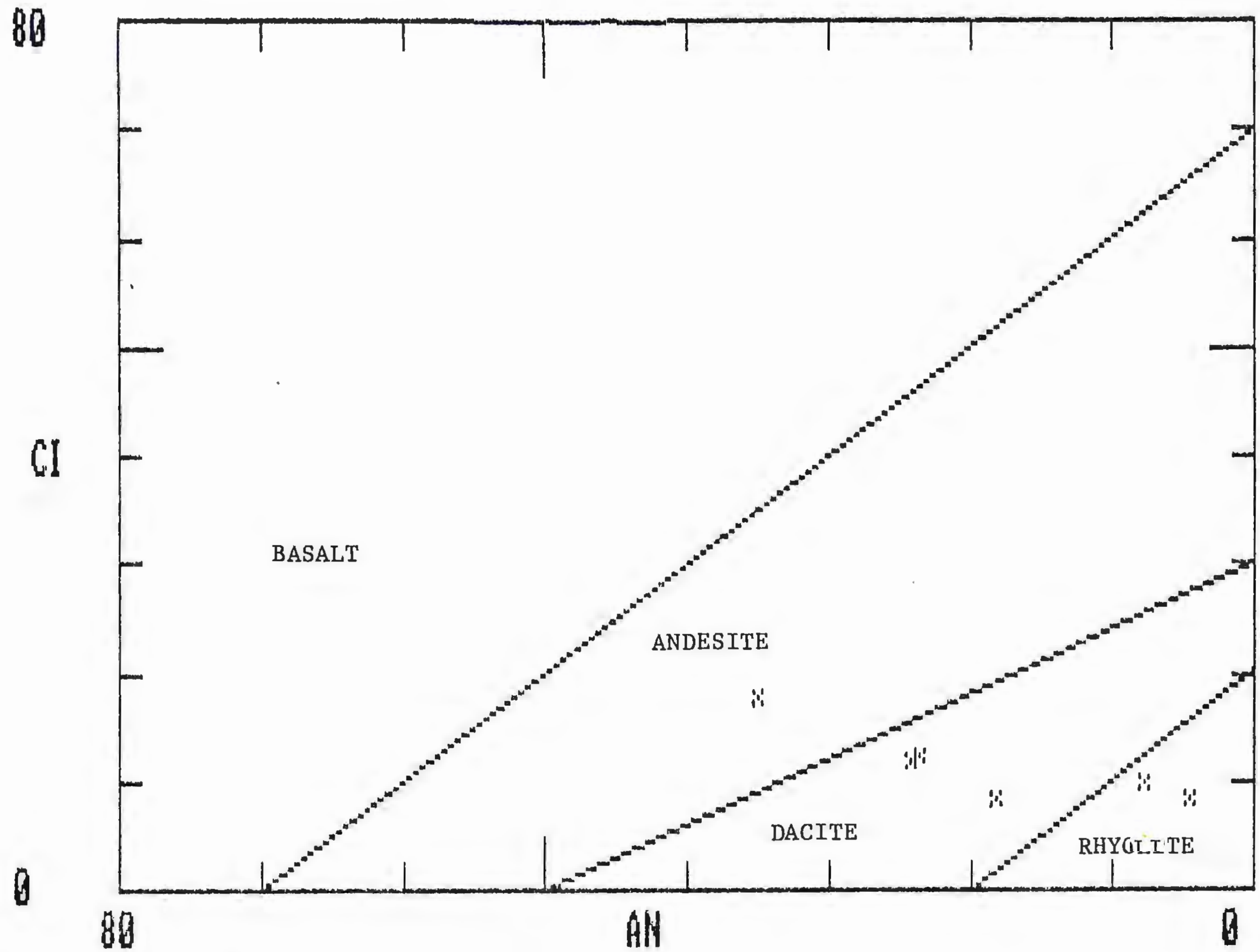

Figure 40: Variation of color index (CI) with normative plagioclase composition (AN), dividing lines after Irvine and Baragar (1971).

tholeiitic and calc-alkaline suites using several different variation diagrams. Most commonly used to differentiate these suites is the AFM diagram which compares the weight percent of the three end members: A= $Na_2O + K_2O$, F= $FeO + 0.8998Fe_2O_3$, M= MgO. The AFM plot for the analyzed samples is shown in Figure 41. Only the sample from the quartz-feldspar porphyry dike (# MSW-11A) falls clearly in the calc-alkaline field; the remainder plot along the dividing line proposed by Irvine and Baragar (1971) to separate the two suites.

The ambiguity of the AFM diagram may indicate that either these rocks are transitional between the two suites, or that the alkali contents of these samples were altered during metamorphism. These samples were also plotted on a Jensen Cation Plot (Jensen, 1976) which does not rely on the alkali content, but instead utilizes the less mobile constituents: Al_2O_3, $FeO + Fe_2O_3 + TiO_2$ and MgO (Fig. 42). The Jensen diagram also shows the quartz-feldspar porphyry dike plotting clearly in the calc-alkalic field while the remainder of the samples plot on or near the line dividing the tholeiitic and calc-alkalic fields. The arrangement of these samples along the dividing line indicates these rocks are transitional between the two suites. However, these samples do appear to correspond to the calc-alkalic trend recognized by Jensen (1976). For this reason, and also

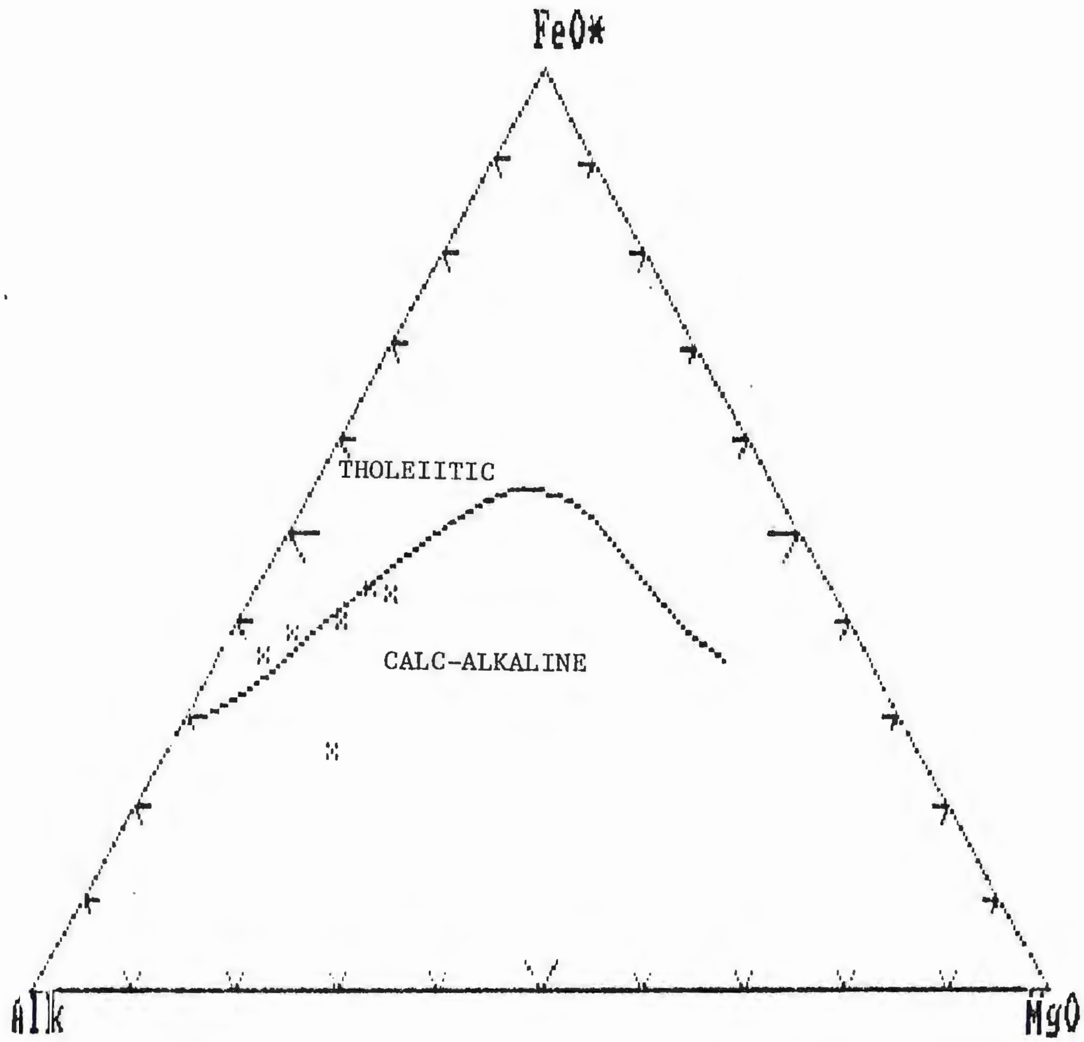

Figure 41: AFM diagram with dividing line between tholeiitic and calc-alkaline fields after Irvine and Baragar (1971).

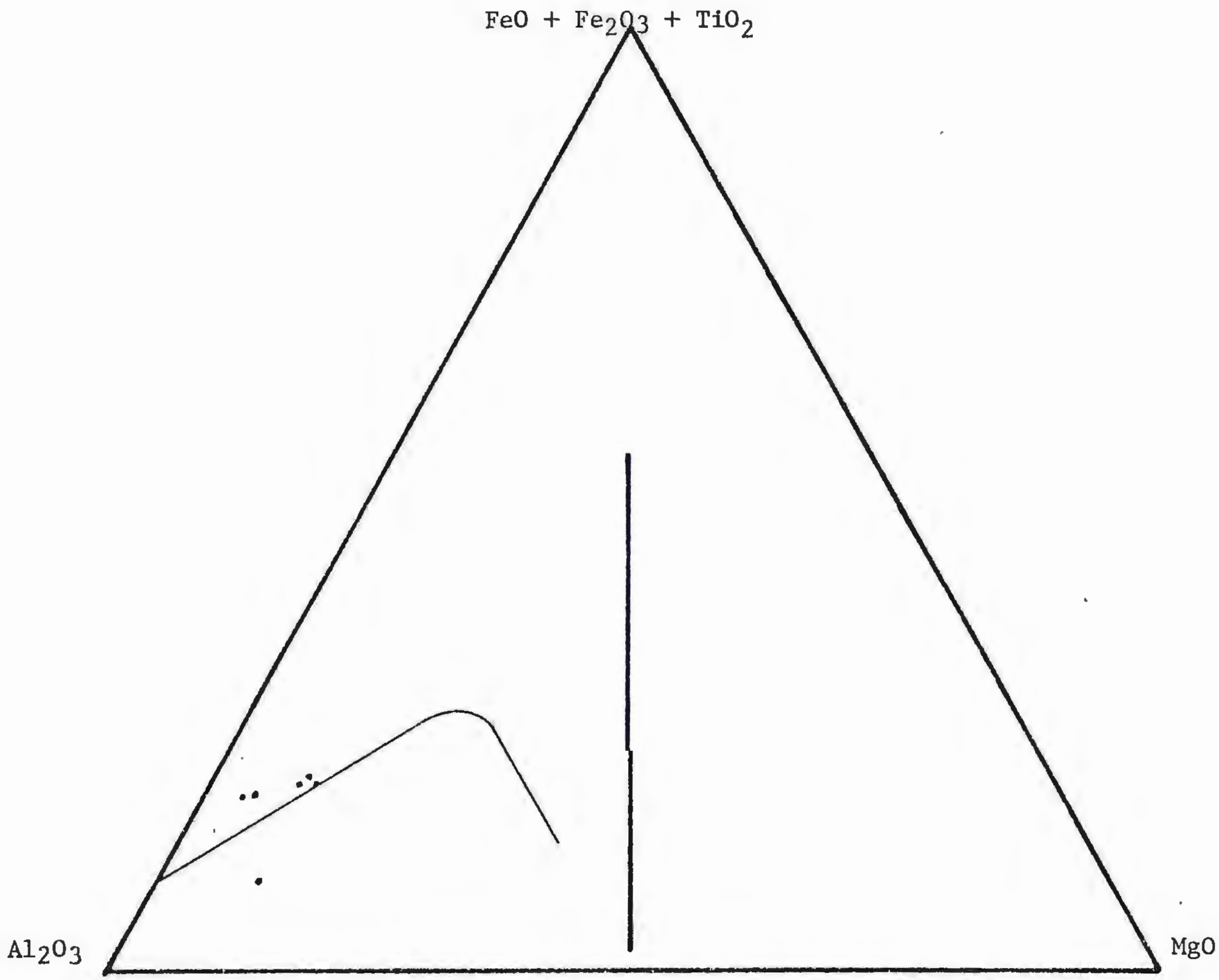

Figure 42: Jensen Cation Plot (after Jensen, 1976) for the study area.

because of the low proportion of mafic flows in the study area, these rocks will be considered as part of a calc-alkaline suite.

The interpretation of these rocks as calc-alkaline volcanics is consistent with Greenberg and Brown's (1983) findings for the bulk of their "Penokean Volcanic Belt", and is also consistent with LaBerge and Myers' (1983) findings for the volcanic rocks of Marathon County.

VII. SEQUENCE INTERPRETATION

Study of the field relationships and the petrographic study suggest a transition within the volcanic succession from dominantly volcanic rocks to rocks of dominantly sedimentary origin and back to dominantly volcanic rocks (segments A, B and C, respectively, of Figures 3 and 4). Explanation of this transition requires the development of a volcanologic model to aid in the interpretation of the sequence.

The easternmost, and presumably oldest, portion of the succession consists of dominantly intermediate to felsic lava flows and pyroclastic flows. The pyroclastic units are mainly massive tuffs and breccias composed of varying percentages of lithic, vitric and crystal fragments. The relationships between the lava flows and the pyroclastic units is unclear; they may have been derived from the same vent at different periods or they may have originated from different vents and simply interfinger within the study area. The upper portion of the lower dominantly volcanic sequence is represented by three units: a fragmental basalt unit, a massive to thinly laminated tuff unit and a dacite lava flow. The fragmental basalt unit has characteristics of deposits formed during phreatomagmatic eruptions caused by the interaction of hot magma or lava flows with water or water-saturated ground. In this case the close stratigraphic proximity to fluvial deposits might suggest that the rising magma encountered the groundwater of the channel-flood plain system. As hot basaltic magma and groundwater come together, it results in quenching and violent explosive steam eruptions which fragments the partially vesiculated magma, this may result in fragmental basalt layers of considerable areal extent (Lajoie, 1979). The laminated to massive tuff unit which overlies the basalt may also be related to the phreatomagmatic eruption, representing fine-grained airfall and surge deposits resulting from increased water to magma ratios (Fisher and Schmincke, 1984). The dacite lava flow that overlies the tuff unit prevented the erosion of the tuff unit, allowing for its preservation.

Unconformably overlying the sequence of volcanic rocks is a sequence of sedimentary and pyroclastic units with a few thin interbedded lava flows. The lowest unit in this sequence is the red volcanic sandstone, derived from older volcanic units; it is composed almost exclusively of volcanic fragments of various compositions and minor felsic plutonic rock fragments. The sandstones are composed of subangular to rounded grains and are cross-bedded. The thin conglomerate beds in this sandstone are very discontinuous, clasts are well-rounded and average less than 5 cm in diameter. This unit probably represents sands and gravels deposited by a braided stream system flowing through the volcanic field. These red sediments grade upward into gray sandstones that are part of the overlying unit, the thinly bedded siltstone and tuff unit.

The siltstone and tuff unit that overlies the red sandstones may represent a change from a fluvial system to a closely associated lacustrine system. The development of a lacustrine setting may occur due to partial damming of a fluvial system by lava or debris flows, or due to subsidence of the volcanic basin (Collinson, 1978). The sediments deposited in this basin have a very limited composition, mainly fine-grained plagioclase, quartz, felsic to intermediate volcanic rock fragments and vitric ash. This material was probably deposited both directly as airfall and as fine-grained material washed into the lake following eruptions. The top of this unit grades into the dark green sandstone and conglomerate unit that represents the return to fluvial processes as the lake basin was filled.

Overlying the siltstone unit is an intercalated sequence of dark green conglomeratic sandstones and pyroclastic deposits. The northern half of the sequence is dominated by sandstones and conglomerates derived mainly from the volcanic sequence and associated shallow plutonics; an older uplifted sedimentary source is also indicated by the presence of quartzite pebbles. These sandstones represent sediments deposited by a braided stream system that flowed through the volcanic field. The andesite flow which is interbedded within this unit apparently was eroded following deposition, because recognizable clasts and boulders of it are seen elsewhere in the sandstone unit.

The southern half of this section is dominated by pyroclastic flows which overlie the tuffaceous siltstones in this area. These pyroclastics were deposited upon unconsolidated sediments, which resulted in compaction due to the weight of the pyroclastic unit and injection of siltstone dikes into the tuffs. This pyroclastic unit has a massive base and is composed primarily of coarse dacitic to andesitic lithic fragments; upward it becomes bedded, finer-grained and more crystal-rich. This trend may be due to the changing style of the eruption. The initial explosive eruption removed the lithic material from the vent allowing the tapping of the magma chamber; this resulted in the deposition of vitric and crystal-rich ash and lapilli tuff. This unit has most of the characteristics of Vulcanian eruptions from strato-volcanoes as described by Williams and McBirney (1979). Vulcanian eruptions commonly end with the expulsion of thick, viscous lava flows or the growth of a lava dome in the vent.

Overlying the ash and lapilli tuff unit is the block-and-ash flow/lahar unit. This unit contains large meter-sized blocks of flow-banded dacite in a matrix of smaller dacite fragments and sericite. This deposit may represent either a Pelean-type pyroclastic flow due to explosion resulting in collapse and fragmentation of a growing dome, or it may represent a lag-fall deposit related to the emplacement of the overlying welded tuff.

The dacite welded tuff unit that overlies the block-and- ash flow is interpreted as a welded, vitric-crystal tuff. The emplacement of this unit may be the result of the unroofing of the magma chamber. This unit is quite homogeneous in appearance, now consisting mainly of plagioclase phenocrysts in a fine-grained, devitrified groundmass. It appears to be unconformably overlain by the volcanic sandstones further to the north. Following the eruption and emplacement of the welded unit, there appears to have been a period of relatively little volcanism, as sandstones, with only minor tuff units, again become dominant.

The preceding sequence of conglomeratic sandstones and pyroclastics is apparently capped by a second sequence of dominantly volcanic rocks. This sequence, like the lowermost sequence, is poorly exposed and consists of intermediate to felsic lava flows and pyroclastics with minor mafic flows.

Volcanic Facies

The characteristics of volcanic rocks and associated sediments tend to vary as distance from the vent increases; these variations can be used to interpret a depositional setting. The types of rocks present in various settings is dependent on the intensity of the eruption and the type of eruptions; variations in these factors results in the gradational and often overlapping nature of volcanic sequences.

Fisher and Schminke (1984) have divided volcanic sequences into three facies dependent on the relative distance to the source. These facies are: the near-source, the intermediate-source and the distant-source facies.

The near-source facies represents the units found immediately around the vent and on the steep slopes of the volcano. These deposits include lava flows and thick, poorly sorted, unbedded pyroclastic deposits. These pyroclastics may originate from different vents on the volcano and may be complexly interbedded with both lava flows and separate pyroclastic flows. Deposits in this facies may be intruded by small stocks and sills and by dikes radiating outward from the central conduit.

The intermediate-source facies consists of pyroclastic flows, lava flows, and airfall tuffs; these may be interbedded with sandstones deposited by braided streams.

With increasing distance from the source the amount of redeposited pyroclastic and epiclastic debris will increase and non-volcanic material becomes more common.

The distant-source facies is represented by layers of fallout ash far from the volcanic center and rare pyroclastic and lava flows. Volcanic units in this facies are typically thin, fine-grained and well sorted layers interbedded with non-volcanic sediments.

The sedimentary sequence described in the study area exhibits most of the characteristics of the intermediate-source facies. The central, dominantly sedimentary section, consists of fluvial and lacustrine deposits formed during a period of decreased volcanism. These sediments were derived primarily from exposed lava flows and unconsolidated pyroclastic deposits. The welded and non-welded pyroclastic deposits associated with these sediments indicates intermittent periods of increased volcanic activity.

The dominantly volcanic sequences, the easternmost and westernmost sections, may represent an interfingering with the near-source facies during periods of intensely active volcanism. The illustration in Figure 43 shows the authors interpretation of the geologic setting for the volcanic succession, prior to the capping of the sequence by the volcanics on the west side of the study area (segment C of Figures 3 and 4).

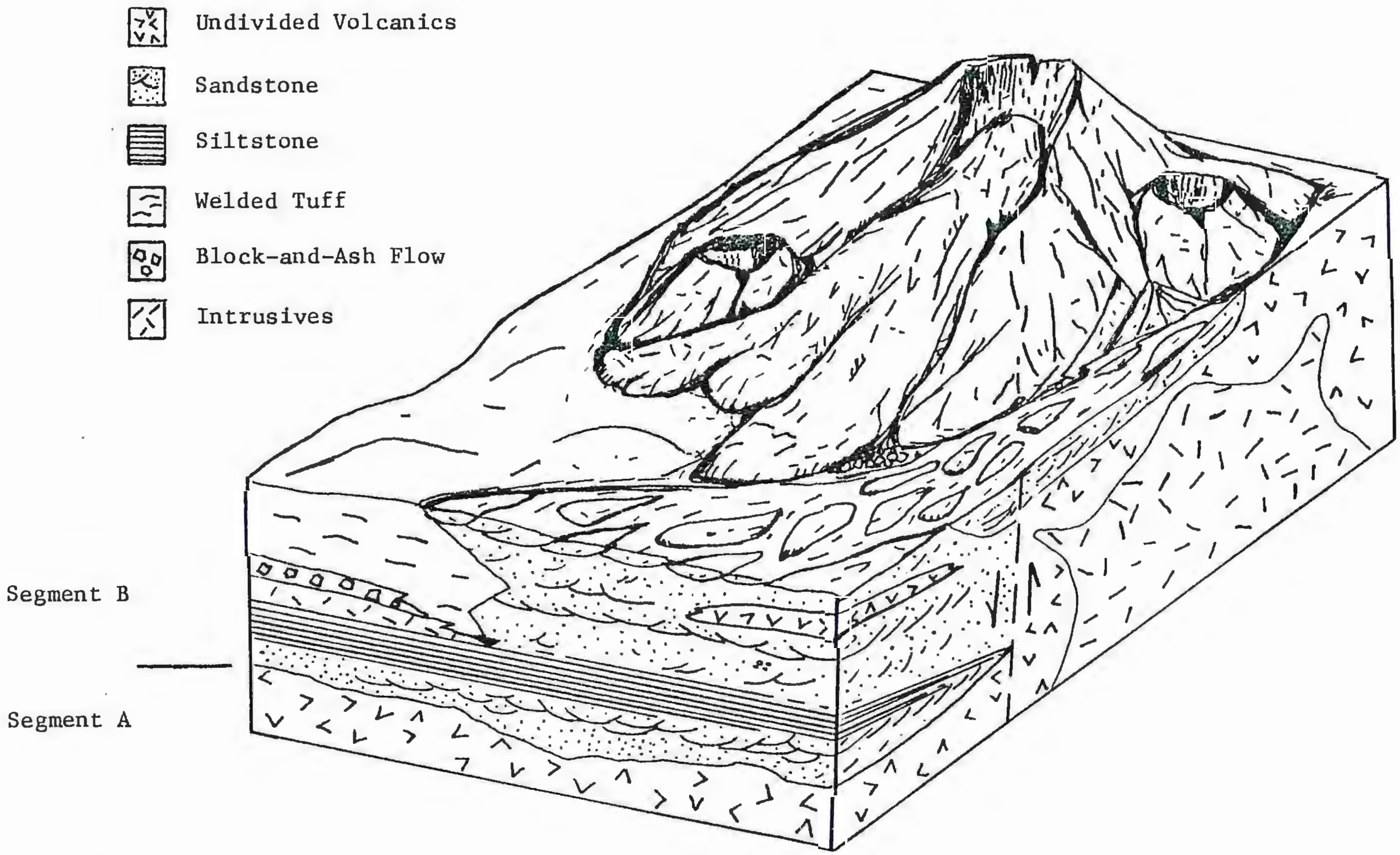

Figure 43: Block diagram showing interpreted geologic setting.

Tectonic Environment and History

The tectonic environment in which the volcanic-plutonic terrane of central and northern Wisconsin formed is not completely understood. These rocks were formed between 1900-1820 m.y. ago (Van Schmus and Bickford, 1981) during Penokean activity in the Lake Superior region. Volcanic rocks in northern Wisconsin and Michigan tend to be older older and chemically different from rocks further south in Wisconsin (Greenberg and Brown, 1983a). The ages and chemical differences of these igneous rocks have been interpreted in terms of plate tectonic processes by many authors including Van Schmus and Bickford (1981), Greenberg and Brown (1983a, 1983b) and LaBerge, Schultz and Myers (1984).

These models begin at the stage following the deposition of stable shelf-type sediments of the Chocolay and Menominee Groups in Upper Michigan on a southward-facing, passive continental margin. The onset of northward subduction in these models is indicated by the deposition of the volcanic rocks of the Baraga Group on the continental margin. Greenberg and Brown propose the development of a continental margin arc and an island arc located further to the south which collide during the Penokean orogeny. LaBerge, Schultz and Myers' model suggests the development of an island arc to the south of the continental margin. Collision of the island arc with an Archean block moving in from the south resulted in the change to southward subduction of the backarc area under the fused island arc-Archean block. Southward subduction continued until collision with the continental margin to the north occurred. This model also suggests a third cycle of volcanic activity following the final collision; this resulted in the deposition of the undeformed volcanic and sedimentary rocks in the study area and surrounding area. They consider these rocks to be "caldera type rocks analogous to basin-and-range volcanic rocks in the Western United States", possibly related to rifting.

The features recognized in the rocks in the study area allow some interpretation of the tectonic environment in which they were deposited. The presence of an estimated 500 m of fluvial conglomeratic sandstones, siltstones with lacustrine affinities, and the absence of volcanic pillowed units indicates a subaerial depositional environment. An emergent environment is atypical for the bulk of the "Penokean Volcanic Belt" which is considered to consist mainly of subaqeously deposited volcanics (Greenberg and Brown, 1983a).

The volcanic rocks in the study area also differ from subaqeously erupted basalts, andesites and pyroclastic units associated with island arcs. The rocks in the study area are typically dacitic to andesitic lava flows and pyroclastic flows. Two of these pyroclastic units are intensely welded which requires subaerial eruption (if not deposition) in order to maintain the heat necessary to cause welding (Fisher and Schmincke, 1984). Volcanic rocks and volcaniclastic rocks of rhyolitic to andesitic composition with minor basalt are most common in continental margin magmatic arcs. An emergent magmatic arc is also indicated by the detrital mode of the dark green conglomeratic sandstone unit, as interpreted from the QFL and QmFLt diagrams after Dickinson et al.(1983). These diagrams (Figs. 24-25) indicate various stages of erosion of the magmatic arc, occasionally reaching the shallow plutons associated with the volcanics. The red sandstone and conglomerate unit, found stratigrapically lower in the section, contains a lower percentage of plutonic rock fragments and may represent an early stage of erosion and deposition in this part of the volcanic field. Uplifts allowing erosion to reach these shallow plutons may be more common for continental margin arcs with thick roots that will allow isostatic rise of the arc, than for oceanic arcs (Dickinson, 1974).

The volcanic facies present in the study area represent dominantly intermediate-source and minor near-source sequences. These facies are directly comparable to the dispersal facies of Dickinson (1974) that may be deposited in back-arc, fore-arc or intra-arc

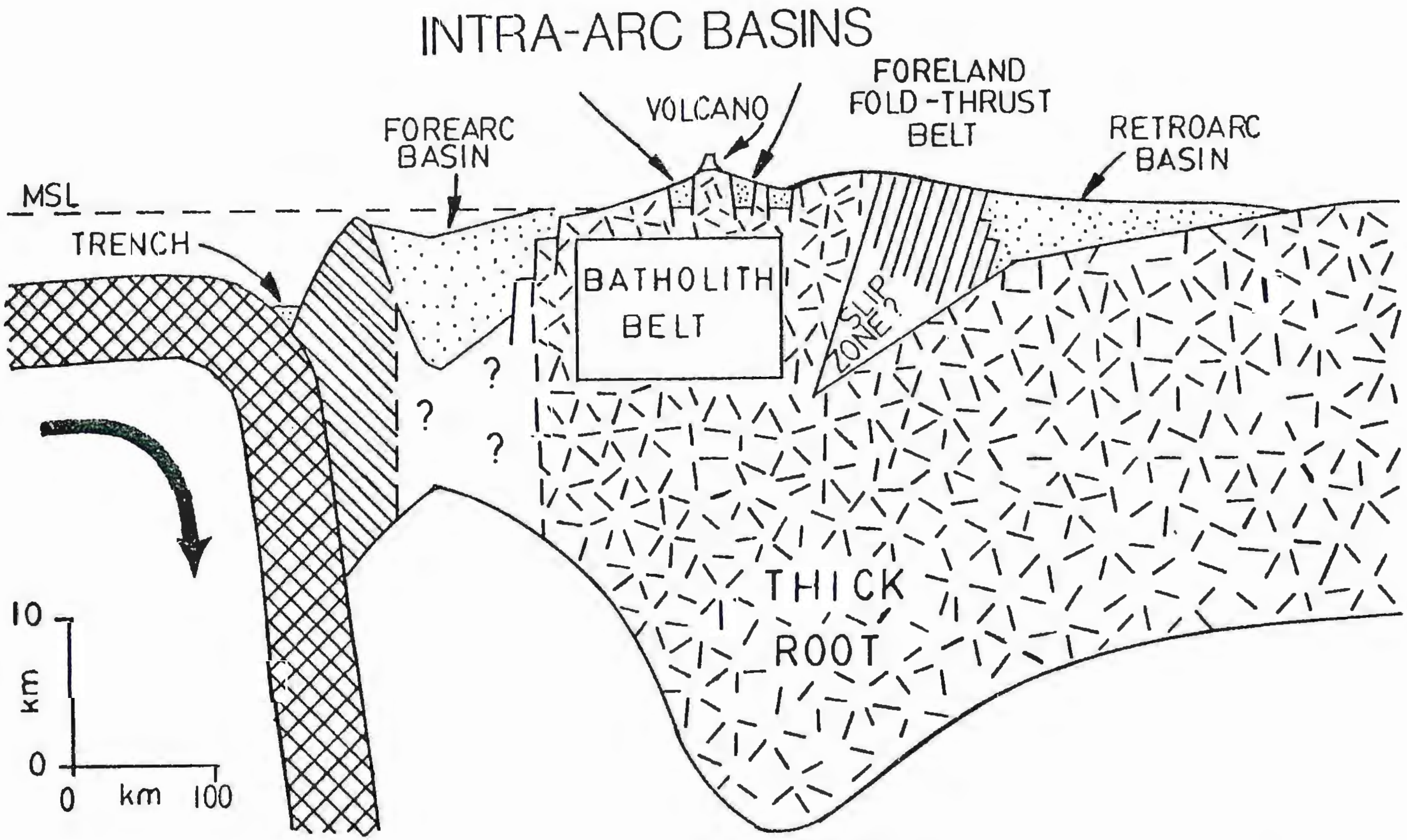

Figure 44: Illustration of sedimentary basins associated with continental magmatic arcs (from Dickinson, 1977).

basins. The relative location of these basin types to the magmatic arc is shown in Figure 44. The deposits that may be associated with these basin types in continental margin arcs have been included below (from Dickinson, 1974).

Intra-arc basins	Volcaniclastic red beds and subaerial tuffs in grabens having lacustrine basin fills, fluvial suites and conglomerates from subaerial volcanoes and local unconformities.
Arc-trench gaps (Fore-arc basins)	Fluviatile, deltaic and prodeltaic beds of coastal plain complexes built upon subsiding shelfs.
Back-arc basins	Piedmont or deltaic wedges, interior seaways and fluvial lowlands of shallow foreland basins.

From these descriptions the volcanic and volcaniclastic rocks in the area around Wausau appear to correspond to intra-arc basin sequences. Intra-arc or intra-massif basins (Dickinson and Seely, 1979) may lie either behind the volcanic complex or in front of it where it is considered a type of fore-arc basin. These basins are generally small and elongate parallel to the axis of the arc and may be fault bounded.

The relatively undeformed nature of these rocks may indicate formation after the main phase of deformation associated with the Penokean orogeny; it may also indicate deposition in a fore-arc region, as these areas are commonly less deformed and metamorphosed than the coeval arc and trench assemblages associated with them (Dickinson, 1974).

The deposition of the rocks in the study area in a localized basin in a fore-arc region may support the southward subduction indicated by LaBerge, Schulz and Myers' (1984) model. As previously described, the initial northward subduction switches to southward subduction following a proposed collision between the island arc and an Archean block. The southward subduction then continues until collision occurs between the northern and southern blocks. The volcaniclastic sequence in this study may represent post-collision volcanics and sediments related to the continued rise of magma after subduction had ceased. This interpretation differs from LaBerge, Schulz and Myers' (1984) model in that it does not require a separate third period of igneous activity but rather a continuation of magmatism related to the southward subduction.

Volcanism from large stratovolcanoes would continue as the felsic magmas neared the surface. These volcanoes were active intermittently and were continually undergoing erosion, which is indicated by tuff and lava flow units are interbedded with dominantly volcanically-derived sediments. These sediments were transported from the east-southeast by a braided river system to an intra-arc basin to the northwest.

The preservation of this intra-arc sequence may be due to minor extension after subduction had ceased. The graben-like structures commonly associated with intra-arc sequences may form due to extension related to the rise of plutons or to the withdrawal of magma from beneath the arc (Dickinson and Seely, 1979). The subsidence of the block would allow burial by subsequent volcanic units, increasing the chances of preservation. Magmatism attributed to the last stages of the Penokean orogeny apparently continued until approximately 1,760 m.y. ago when volcanism and emplacement of plutons occurred in south-central Wisconsin (Smith, 1978). This period of magmatism is considered post-Penokean by Anderson, Cullers and Van Schmus (1980), who consider it a change to anorogenic tectonism.

The magmatism in Wisconsin was followed by a period of stability that allowed deep erosion and weathering of the igneous, metamorphic and sedimentary rocks. The reworking of the sediments derived from these rocks in fluvial and shallow marine environments resulted in the deposition of the quartzites of the "Baraboo Interval" on a passive continental margin (Dott, 1983). These quartzites underwent a period of metamorphism and deformation between 1,615-1,630 m.y. ago that may have occurred during collision of the passive continental margin with a magmatic arc moving in from the south (Dott, 1983). This event may also have caused part of the metamorphism and deformation seen in the study area.

The deformation and metamorphism of the quartzites was followed by emplacement of the 1,500 m.y. old Wolf River Batholith and the associated syenites located near Wausau. These plutons are considered anorogenic and were emplaced during post-Penokean crustal extension (Anderson et al., 1980). The emplacement of these plutons is apparently the last magmatic event to affect the rocks in the study area.

Conclusions

Significant conclusions which can be drawn from this study include:

1) The dominant volcanic rocks in the study area are andesitic to dacitic lava flows and pyroclastics. Basaltic rocks are a minor component of the exposed sequence.

2) The lack of pillowed basalt units and the presence of welded pyroclastic flows indicates eruption of the volcanic units in a subaerial environment.

3) Three distinct volcanic units are present in the 3M quarry, a nonwelded pyroclastic unit, a block-and-ash flow, and a welded tuff. The nonwelded unit is lithic-rich at its base and becomes crystal-rich higher in the unit. The upper portion of this unit also contains thin airfall ash layers. The trend of pyroclastic units from lithic-rich to crystal-rich is typical of deposits formed due to Vulcanian eruptions. The block-and-ash flow that caps the nonwelded unit may represent material derived from the breakup of a lava dome that formed in the summit crater following the initial eruption, or a coarse lag-fall deposit related to the emplacement of the overlying welded tuff. The welded tuff that overlies the block-and-ash flow may represent the deposit formed due to the unroofing of the magma chamber during renewed volcanic

eruptions.

4) There are two sandstone and conglomerate units recognized in the study area. They are most easily distinguished by their color, greenish-black vs. red, but are also distinct based on their modal components. The red sandstones and conglomerates are composed mainly of felsic volcanic rock fragments (30-60%) and quartz (10-30%). Plagioclase feldspar is a minor component, averaging less than 5%. Plutonic rock fragments and quartzite clasts are very minor components.

The greenish-black sandstones are composed mainly of felsic to intermediate volcanic rock fragments. The plagioclase and quartz contents of this unit averages, 13% and 16%, respectively. Plutonic rock fragments average 3.5%, quartzite grains average 1% to 2% of this unit.

The conglomerates associated with these sandstones are clast-supported and composed of well rounded pebbles, cobbles and boulders. They are also discontinuous, lense-like beds, which often appear to have been deposited in channels.

The red sandstones and conglomerates are derived mainly from the underlying volcanic sequence and very minor hypabyssal intrusives associated with those volcanics. No major outside source of material is indicated or required.

The greenish-black sandstones and conglomerates have a wider range of rock fragment composition, but are mainly locally derived. The greater percentage of plutonic rock fragments indicates that the depth of erosion increased during the interval between the deposition of the red sandstones and the greenish-black sandstones.

5) Paleocurrent study of the greenish-black sandstone unit yielded a strong unimodal paleocurrent pattern, with flow direction to the west-northwest. The variance calculated for the 72 paleocurrent measurements collected is a low 1704, which is most typical of braided fluvial systems.

6) The thinly bedded siltstone and tuff unit overlies the red sandstones and partially underlies the greenish-black sandstones. This unit appears to be gradational with both of these sandstone units and is interpreted as a temporary lacustrine basin in a dominantly fluvial environment. The majority of the sediment is dominantly locally derived volcanic ash. A portion of this material was deposited directly into the lake, but the majority was probably deposited on land and washed into the basin following eruptions.

7) The volcanic and sedimentary succesion within the study area is tilted to the west at 10-30° and is otherwise relatively undeformed. These volcanics and volcanic sediments have been metamorphosed to lower greenschist facies.

8) Petrochemical data from 6 volcanic rock samples indicate this is a subalkaline suite. These samples plot on or near the boundary between the tholeiitic and calc-alkaline fields, but exhibit a calc-alkaline trend.

9) The tectonic setting is interpreted as a north-facing, continental margin magmatic arc, with a south dipping subduction zone (after Laberge, Schulz and Myers, 1984) located to the north. The depositional setting for the area of study is interpreted as a restricted, possibly fault bounded, basin within the volcanic field (an intra-arc basin). These rocks were apparently deposited after the main phase of deformation associated with the Penokean Orogeny.

REFERENCES CITED

Anderson, J.L., Van Schmus, W.R., and Medaris, L.G., 1975, Proterozoic granitic plutonism in the Lake Superior region and its tectonic implication: [Abs.]: EOS Am. Geophys. Union Trans.), v. 56, p.603.

Anderson, J.L., Cullers, R.L., and Van Schmus, W.R., 1980. Anorogenic metaluminous and peraluminous granite plutonism in the mid-Proterozoic of Wisconsin, U.S.A.: Contributions to Mineralogy and Petrology, v. 74, p. 311-328.

Asquith, G.B., 1963, Origin of the Precambrian Wisconsin rhyolites: Journal of Geology, v. 72, p. 835-847.

Cambray, F.W., 1978, Plate-tectonics as a model for the environment of sedimentation of the Marquette Range Supergroup and the subsequent deformation and metamorphism associated with the Penokean Orogeny [abs.]: 24th Institute on Lake Superior Geology, Milwaukee, p. 6.

Cant, D.J., 1982, Fluvial facies models and their application. In: Scholle, P.A., and Spearing, D., ed., Sandstone depositional enviroments: AAPG Memoir 31, p. 115-138.

Collinson, J.D., 1978, Alluvial Sediments. In: Reading, H.G., ed., Sedimentary environments and facies: Elsevier, p. 15-79.

Dickinson, W.R., 1974, Sedimentation within and beside ancient and modern magmatic arcs. In: Dott, R.H., Jr., and Shaver, R.H., eds., Modern and ancient geosynclinal sedimentation: Soc. Econ. Paleont. Mineral. Sp. Publ. 19, p. 230-239.

Dickinson, W.R. and Seely, D.R., 1979, Structure and stratigraphy of forearc regions: AAPG Bull., v.63, p. 2-31.

Dickinson, W.R. and Suczek, C.A., 1979, Plate tectonics and sandstone compositions: AAPG Bull., v. 63, p.2164-2182.

Dickinson, W.R., Beard, L.S., Brakenridge, G.R., Erjavec, J.L., Ferguson, R.C., Inman, K.F., Knepp, R.A., Lindberg, F.A., Ryberg, P.T., 1983, Provenance of North American Phanerozoic sandstones in relation to tectonic setting: Geological Society of America Bulletin, v. 94, p. 222-235.

Dickinson, W.R., 1984, Interpreting provenance relations from detrital modes of sandstones: In: Zuffa, G.G., ed., Provenance of Arenites: D. Reidel Publishing Co., p. 333-361.

Dott, R.H., Jr., 1983, The Proterozoic red quartzite enigma in the north central United States: Resolved by plate collision?: Geological Society of America Memoir 160, p. 129-141.

Emmons, R.C., and Snyder, F.G., 1944, A structural study of the Wausau area: Unpublished report on file at Wisconsin Geological and Natural History Survey, 16p.

Fisher, R.V., 1960, Classification of volcanic breccias: Bulletin of the Geological Society of America, v. 72, p. 973-982.

Fisher, R.V., 1961, Proposed classification of volcaniclastic sediments and rocks: Geological Society of America Bulletin, v. 72, p. 1409-1414.

Fisher, R.V., 1966, Rocks composed of volcanic fragments and their classification: Earth-Sci. Rev., 1, p. 287-298.

Fisher, R.V., and Schmincke, H.-U., 1984, Pyroclastic Rocks: Springer-Verlag, Berlin, Heidelberg, New York, Tokyo, 472p.

Goldich, S.S., Nier, A.D., Baadsgaard, H., Hoffman, J.H., and Krueger, H.W., 1961, Precambrian geology and geochronology of Minnesota: Minnesota Geol. Survey Bull. v. 41, 193p.

Greenberg, J.K., and Brown, B.A., 1983a, Lower Proterozoic volcanic rocks and their setting in the southern Lake Superior District: Geological Society of America Memoir 160, p. 67-84.

Greenberg, J.K., and Brown, B.A., 1983b, Cratonic sedimentation during the Proterozoic: An orogenic connection in Wisconsin and the upper midwest: Journal of Geology, v. 92, p.159-171.

Jensen, L.S., 1976, A new cation plot for classifying subalkalic volcanic rocks: Ontario Division of Mines Misc. Paper 66, p. 1-22.

Kuniyoshi, S. and Liou, J.G., 1976, Contact metamorphism of the Karmutsen volcanics, Vancouver Island, British Columbia: Jour. Petrology, v. 17, p. 73-99.

LaBerge, G.L., and Myers, P.E., 1983, Precambrian geology of Marathon County, Wisconsin: Wisconsin Geological and Natural History Survey Information Circular 45, 88p.

LaBerge, G.L., and Myers, P.E., 1984, Two early Proterozoic successions in central Wisconsin and their tectonic significance: Geological Society of America Bulletin, v. 95, p. 246-253.

LaBerge, G.L., Schulz, K.J., and Myers, P.E., 1984, The plate tectonic history of north central Wisconsin [abs.]: Annual Institute on Lake Superior Geology, p. 25-27.

LaBerge, G.L., and Mudrey, M.G., Jr., 1979, Status Report-Stratigraphic framework of the Wisconsin Middle Precambrian: Wisconsin Geological and Natural History Survey Miscellaneous Paper 79-1, 22p.

Lajoie, J., 1972, Slump fold axis orientations: An indication of paleoslope?: Journal of Sedimenary Petrology, v.42, p. 584-586.

Lajoie, J., 1979, Facies Models 15. Volcaniclastic rocks: Geoscience Canada, v. 6, p. 129-139.

Larue, D.K., and Sloss, L.L., 1980, Early Proterozoic sedimentary basins of the Lake Superior region: Geological Society of America Bulletin, Part II, v. 91, p. 1836-1874.

Maass, R.S., 1983, Early Proterozoic tectonic style in central Wisconsin: Geological Society of America Memoir 160, p.85-95.

Morton, R.L. 1986, Personal communication. Universtiy of Minnesota-Duluth.

Mudrey, M.G., and Myers, P.E., 1985, Proterozoic dike swarms in Wisconsin [abs.]: 31st Institute on Lake Superior Geology, Kenora, Ont., p. 66.

Pettijohn, F.J., 1975, Sedimentary Rocks: Third Edition, Harper and Row, New York, 628 p.

Picard, M.D., and High, L.R., Jr., 1972, Criteria for recognizing lacustrine rocks. In: Rigby, J.K., and Hamblin, H.K., eds., Ancient sedimentary environments: SEPM Special Publ. 16, p. 108-145.

Potter, P.E., and Pettijohn, F.J., 1977, Paleocurrents and Basin Analysis: 2nd ed., Springer-Verlag, Berlin, Heidelberg, New York, 425p.

Ross, C.S., and Smith, R.L., 1961, Ash flow tuffs: their origin, geologic relations and identification: U.S. Geol. Survey Prof. Paper 366, 77p.

Rust, B.R., 1981, Facies Models 2. Coarse alluvial deposits: In: Walker, R.G., ed., Geoscience Canada Reprint Series 1, p. 9-22.

Schmid, R., 1981, Descriptive nomenclature and classification of pyroclastic deposits and fragments: Recommendations of the I.U.G.S. Subcommision on the Systematics of Igneous Rocks: Geology, v. 9, p.41-43.

Selley, R.C., 1976, An introduction to sedimentology: Academic Press, 408 p.

Smith, E.I., 1978, Precambrian rhyolites and granites in south central Wisconsin: field relations and geochemistry: Geol.Soc.America Bull., v. 89, p. 875-890.

Smith, R.L., 1966, Zones and zonal variations in welded ash flows :U.S. Geol. Survey Prof. Paper 354-F, p. 149-159.

Turner, F. J., 1981, Metamorphic Petrology: Second Edition, McGraw-Hill Co., 524pp.

Van Schmus, W.R., 1980, Chronology of igneous rocks associated with the Penokean orogeny in Wisconsin: Geological Society of America Special Paper 182, p. 159-168.

Van Schmus, W.R., 1981, Proterozoic chronology and evolution of the midcontinent region: In Kroner, A., ed., Precambrian plate tectonics: Elsevier, p.261-296.

Van Schmus, W.R., Thurman, M.E., and Peterman, Z.E., 1975, Geology and Rb-Sr Chronology of middle Precambrian rocks in eastern and central Wisconsin: Geological Society of America Bulletin, v. 86, p.1255-1265.

Weidman, S., 1907, The geology of north-central Wisconsin: Wisconsin Geological and Natural History Survey Bulletin, v. 16, 697p.

Weis, L.W., and LaBerge, G.L., 1969, Central Wisconsin volcanic belt: 15th Annual Institute on Lake Superior Geology Guidebook, 30p.

Williams, H., and McBirney, A.R., 1979, Volcanology: Freeman, Cooper and Co., San Francisco, 391p.

Winkler, H. G. F., 1979, Petrogenesis of metamorphic rocks: Fifth Edition, Springer-Verlag New York Inc., 348pp.

Wright, J.V. and Walker, G.P.L., 1977, The ignimbrite source problem: significance of a co-ignimbrite lag-fall deposit: Geology, v. 5, p. 729-732.

APPENDIX I: SAMPLE LOCATIONS

ROCK TYPE	ABBREVIATION
Volcanic Sandstone	Volc. Ss.
Conglomerate	Cgl.
Quartz Monzonite	Q. Monz.
Thinly-Bedded Tuff	T-B Tuff
Syenitized Basalt	Sy. Basalt
Amygdaloidal Basalt	Am. Basalt
Fragmental Basalt	Frag. Basalt
Porphyritic Andesite	Por. Andesite
Quartz-Feldspar Porphyry Dike	Q-F Por. Dike
Sericitized Sandstone/Tuff	Ser. Ss./Tuff
Outcrop	(O)
Angular Float	(F)
Test Pit	(T.P.)

SPL #	ROCK TYPE		LOCATION
W84-1	Volc. Ss.	(F)	SW 1/4, SW 1/4, Sec. 34, T. 30 N., R. 7 E.
W84-2	Volc. Ss.	(F)	" "
W84-3	Volc. Ss.	(F)	SE 1/4, NE 1/4, Sec. 4, T. 29 N., R. 7 E.
W84-4	Syenite	(F)	" "
W84-5	Tuff	(F)	" "
W84-6	Volc. Ss	(F)	NW 1/4, NW 1/4, Sec. 3, T. 29 N., R. 7 E.
W84-7	Volc. Ss	(O)	" "
W84-8	Q. Monz.	(F)	SW 1/4, NW 1/4, Sec. 34, T. 30 N., R. 7 E.
W84-9	T-B Tuff	(F)	NW 1/4, SW 1/4, Sec. 34, T. 30 N., R. 7 E.
W84-10	Volc. Ss.	(O)	SE 1/4, SE 1/4, Sec. 33, T. 30 N., R. 7 E.
W84-11	Q. Monz.	(O)	NW 1/4, SE 1/4, Sec. 33, T. 30 N., R. 7 E.
W84-12	Syenite	(O)	NW 1/4, SW 1/4, Sec. 33, T. 30 N., R. 7 E.

APPENDIX 1. (continued)

SPL #	ROCK TYPE		LOCATION
W84-13	Sy. Basalt	(O)	NE 1/4, SW 1/4, Sec. 33, T. 30 N., R. 7 E.
W84-14	Volc. Ss.	(F)	NE 1/4, NW 1/4, Sec. 4, T. 29 N., R. 7 E.
W84-15	Tuff	(F)	" "
W84-16	Cgl.	(F)	" "
W84-17	Cgl.	(F)	" "
W84-18	Dacite	(O)	" "
W84-19	Basalt	(O)	NW 1/4, SE 1/4, Sec. 33, T. 30 N., R. 7 E.
W84-20	Volc. Ss.	(F)	NE 1/4, NW 1/4, Sec. 4, T. 29 N., R. 7 E.
W84-21	Sy. Basalt	(F)	NW 1/4, NW 1/4, Sec. 4, T. 29 N., R. 7 E.
W84-22	Sy. Basalt	(O)	SW 1/4, SW 1/4, Sec. 33, T. 30 N., R. 7 E.
W84-23	Q Monz.	(O)	" "
W84-24	Volc. Ss.	(O)	SE 1/4, NW 1/4, Sec. 3, T. 29 N., R. 7 E.
W84-25	Cgl.	(O)	" "
W84-26	T-B Tuff	(O)	NE 1/4, SW 1/4, Sec. 34, T. 30 N., R. 7 E.
W84-27	T-B Tuff	(O)	" "
W84-28	Volc. Ss.	(O)	NE 1/4, NE 1/4, Sec. 3, T. 30 N., R. 7 E.
W84-29	Volc. Ss.	(O)	SW 1/4, SW 1/4, Sec. 35, T. 30 N., R. 7 E.
W84-30	Volc. Ss.	(O)	SW 1/4, SW 1/4, Sec. 35, T. 30 N., R. 7 E.
W84-31	Cgl.	(O)	" "
W84-32	Volc. Ss.	(O)	NW 1/4, SE 1/4, Sec. 35, T. 30 N., R. 7 E.
W84-33	Cgl.	(O)	SW 1/4, SE 1/4, Sec. 35, T. 30 N., R. 7 E.
W84-34	Volc. Ss.	(O)	" "
W84-35	Am. Basalt	(O)	NW 1/4, SE 1/4, Sec. 35, T. 30 N., R. 7 E.
W84-36	Volc. Ss.	(O)	" "
W84-37	Lapilli Tuff	(O)	" "
W84-38	Red Volc. Ss.	(O)	" "
W84-39	Lapilli Tuff	(O)	" "
W84-40	Red Volc. Ss.	(O)	" "

APPENDIX 1. (continued)

SPL #	ROCK TYPE		LOCATION
W84-41	T-B Tuff	(F)	NW 1/4, SE 1/4, Sec. 35, T. 30 N., R. 7 E.
W84-42	Dacite	(O)	NE 1/4, SE 1/4, Sec. 35, T. 30 N., R. 7 E.
W84-43	Red Volc. Ss.	(O)	SW 1/4, SE 1/4, Sec. 35, T. 30 N., R. 7 E.
W84-44	Red Volc. Ss.	(O)	" "
W84-45	Tuff	(F)	NE 1/4, SE 1/4, Sec. 35, T. 30 N., R. 7 E.
W84-46	Frag. Basalt	(O)	" "
W84-47	Granite	(F)	SE 1/4, NE 1/4, Sec. 35, T. 30 N., R. 7 E.
W84-48	Massive Tuff	(O)	NE 1/4, SE 1/4, Sec. 35, T. 30 N., R. 7 E.
W84-49	Basalt	(O)	" "
W84-50	Massive Tuff	(F)	NW 1/4, SW 1/4, Sec. 36, T. 30 N., R. 7 E.
W84-51	Red Cgl./Tuff	(T.P.)	NW 1/4, SE 1/4, Sec. 36, T. 30 N., R. 7 E.
W84-52	Red Cgl./Tuff	(T.P.)	" "
W84-53	Lapilli Tuff	(O)	SW 1/4, NW 1/4, Sec. 12, T. 29 N., R. 7 E.
W84-54	Crystal Tuff	(O)	" "
W84-55	Siltstone	(F)	NW 1/4, NW 1/4, Sec. 12, T. 29 N., R. 7 E.
W84-56	Volc. Ss.	(O)	NW 1/4, SE 1/4, Sec. 2, T. 29 N., R. 7 E.
W84-57	Por. Andesite	(O)	" "
W84-58	Siltstone	(O)	NW 1/4, NE 1/4, Sec. 12, T. 29 N., R. 7 E.
W84-59	Siltstone	(O)	" "
W84-60	Lapilli Tuff	(O)	" "
W84-61	Q-F Por. Dike	(O)	" "
W84-62	Lithic Tuff	(F)	NW 1/4, NW 1/4, Sec. 1, T. 29 N., R. 7 E.
W84-63	Siltstone	(O)	NE 1/4, SE 1/4, Sec. 2, T. 29 N., R. 7 E.
W84-64	Siltstone	(O)	" "
W84-65	Lithic Tuff	(O)	NW 1/4, NW 1/4, Sec. 12, T. 29 N., R. 7 E.
W84-66	Lithic Tuff	(O)	NW 1/4, NW 1/4, Sec. 12, T. 29 N., R. 7 E.
W84-67	Siltstone Dike	(O)	" "
W84-68	Lapilli Tuff	(O)	NW 1/4, SE 1/4, Sec. 35, T. 30 N., R. 7 E.

APPENDIX 1. (continued)

SPL #	ROCK TYPE		LOCATION
W84-69	Lithic Tuff	(O)	NW 1/4, NW 1/4, Sec. 2, T. 29 N., R. 7 E.
W84-70	Por. Andesite	(O)	SE 1/4, NW 1/4, Sec. 2, T. 29 N., R. 7 E.
W84-71	Volc. Ss.	(O)	NW 1/4, SE 1/4, Sec. 2, T. 29 N., R. 7 E.
W84-72	Volc. Ss.	(O)	" "
W84-73	Volc. Ss.	(O)	NE 1/4, NE 1/4, Sec. 3, T. 29 N., R. 7 E.
W84-74	Volc. Ss.	(O)	" "
W84-75	Volc. Ss.	(O)	SW 1/4, SW 1/4, Sec. 35, T. 30 N., R. 7 E.
W84-76	Siltstone	(O)	SW 1/4, SE 1/4, Sec. 35, T. 30 N., R. 7 E.
W84-77	Volc. Ss.	(O)	SW 1/4, SW 1/4, Sec. 35, T. 30 N., R. 7 E.
W84-78	Red Cgl./Tuff	(O)	NW 1/4, SE 1/4, Sec. 36, T. 30 N., R. 7 E.
W84-79	Por. Andesite	(O)	SE 1/4, SW 1/4, Sec. 31, T. 30 N., R. 8 E.
W84-80	Lithic Tuff	(O)	" "
W84-81	Dacite	(F)	" "
W84-82	Basalt	(O)	SW 1/4, NW 1/4, Sec. 6, T. 29 N., R. 7 E.
W84-83	Lithic Tuff	(F)	" "
W84-84	Lithic Tuff	(F)	NW 1/4, SE 1/4, Sec. 1, T. 29 N., R. 7 E.
W84-85	Welded Tuff	(O)	NW 1/4, NE 1/4, Sec. 12, T. 29 N., R. 7 E.
W84-86	Lithic Tuff	(O)	NE 1/4, SW 1/4, Sec. 12, T. 29 N., R. 7 E.
W84-87	Lithic Tuff	(O)	SE 1/4, SW 1/4, Sec. 6, T. 29 N., R. 7 E.
W84-88	Lithic Tuff	(O)	" "
W84-89	Frag. Basalt	(O)	NE 1/4, SE 1/4, Sec. 36, T. 30 N., R. 7 E.
W84-91	Cgl.	(O)	SW 1/4, SW 1/4, Sec. 3, T. 29 N., R. 7 E.
W84-92	Volc. Ss.	(O)	" "
W84-93	Dacite	(O)	NE 1/4, NW 1/4, Sec. 14, T. 29 N., R. 7 E.
W84-94	Dacite	(O)	SW 1/4, SW 1/4, Sec. 10, T. 29 N., R. 7 E.
W84-95	Dacite	(O)	" "
W84-96	Dacite	(O)	NW 1/4, SW 1/4, Sec. 10, T. 29 N., R. 7 E.
W84-97	Cgl.	(O)	SE 1/4, NW 1/4, Sec. 3, T. 29 N., R. 7 E.
W84-98	Siltstone	(O)	SW 1/4, SW 1/4, Sec. 3, T. 29 N., R. 7 E.

APPENDIX 1. (continued)

SPL #	ROCK TYPE		LOCATION
W84-99	Volc. Ss.	(O)	SW 1/4, SW 1/4, Sec. 3, T. 29 N., R. 7 E.
W84-100	Volc. Ss.	(O)	" "
W84-101	Basalt Dike	(O)	NW 1/4, SW 1/4, Sec. 3, T. 29 N., R. 7 E.
W84-102	Basalt Dike	(O)	" "
W84-103	Lithic Tuff	(O)	SW 1/4, SW 1/4, Sec. 3, T. 29 N., R. 7 E.
W84-104	Crystal Tuff	(O)	NW 1/4, SE 1/4, Sec. 10, T. 29 N., R. 7 E.
W84-105	Dacite	(O)	" "
W84-106	Dacite	(O)	" "
W84-107	Volc. Ss.	(O)	" "
W84-108	Ser. Ss./Tuff	(O)	NW 1/4, SW 1/4, Sec. 3, T. 29 N., R. 7 E.
W84-109	Welded Tuff	(O)	NE 1/4, SE 1/4, Sec. 3, T. 29 N., R. 7 E.
W84-110	Welded Tuff	(O)	" "
W84-111	Basalt	(F)	NW 1/4, SW 1/4, Sec. 7, T. 29 N., R. 8 E.
W84-115	Volc. Ss.	(O)	NW 1/4, SW 1/4, Sec. 3, T. 29 N., R. 7 E.
W84-116	Dacite Dike	(O)	" "
W84-117	Dacite Dike	(O)	" "
W84-118	Dacitic Tuff	(O)	" "
W84-119	Siltstone	(O)	" "
W84-120	Cgl.	(O)	SW 1/4, NW 1/4, Sec. 3, T. 29 N., R. 7 E.
W84-121	Welded Tuff	(O)	" "
W84-122	Volc. Ss.	(O)	NE 1/4, SE 1/4, Sec. 3, T. 29 N., R. 7 E.
W84-123	Volc. Ss.	(O)	" "
W84-124	Volc. Ss.	(O)	SE 1/4, NW 1/4, Sec. 3, T. 29 N., R. 7 E.
W84-125	Volc. Ss.	(O)	" "
W84-126	Volc. Ss.	(O)	NE 1/4, SE 1/4, Sec. 3, T. 29 N., R. 7 E.
W84-127	Welded Tuff	(O)	" "
W84-128	Volc. Ss.	(O)	" "
W84-129	Volc. Ss.	(O)	SW 1/4, SW 1/4, Sec. 3, T. 29 N., R. 7 E.
W84-130	Dacitic Tuff	(O)	" "

APPENDIX 1. (continued)

SPL #	ROCK TYPE		LOCATION
RRT-1	Por. Andesite	(O)	SE 1/4, NW 1/4, Sec. 2, T. 29 N., R. 7 E.
3M-68	Rhyolite	(O)	NW 1/4, Sec. 11, T. 29 N., R. 7 E.
(Analyses for samples RRT-1 and 3M-68 from LaBerge and Myers, 1983)			
MSW-10A	Lapilli Tuff	(O)	NW 1/4, SW 1/4, Sec. 3, T. 29 N., R. 7 E.
MSW-10B	Lithic Tuff	(O)	" "
MSW-10C	Lithic Tuff	(O)	" "
MSW-11A	Q-F Por. Dike	(O)	NW 1/4, NE 1/4, Sec. 12, T. 29 N., R. 7 E.